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Technical Note 42

ANALOG-DIGITAL CONVERSION EQUIPMENT FOR ELECTROCARDIOGRAPHIC DATA

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS
Technical Note

42

APRIL 1960

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L. Taback

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ABSTRACT

A corrected orthogonal 3-lead system has been used to record electrocardiograms directly from patients at Veterans Hospitals, using three FM channels of magnetic tape. A pilot facility has been designed and assembled by NBS to permit a medical technician to inspect these on an oscilloscope and select a significant cardiac cycle. This is automatically sampled at millisecond intervals and the numerical values are stored in digital form on magnetic tape acceptable to an electronic computer. Upon writing various programs for the digital computer, the cardiac researcher will have a flexible tool for objective analysis of large quantities of biological data by a variety of possible criteria.

ANALOG-DIGITAL CONVERSION EQUIPMENT FOR ELECTROCARDIOGRAPHIC DATA

by

L. Taback

1.0 INTRODUCTION

Under a Veterans Administration research program, the National Bureau of Standards has designed and assembled a pilot facility for monitoring electrocardiographic data taken in analog form on magnetic tape and converting it to a digital magnetic tape format for automatic analysis by a digital computer. There are several good reasons for taking this approach to the study of heart signals.

(1) The method will make possible a completely objective analysis, by eliminating the effect of variations in interpretation by individual observers.

(2) Fidelity of the data is maintained both in accuracy and in dynamic range. Conventional methods of cardiographic analysis are conducive to large errors in amplitude measurements and also large errors in time relationships. In addition, many of the paper records do not have a wide enough frequency band and consequently lose the higher-frequency components in the signals.

(3) The method will permit the convenient storage of large amounts of data. Equally important, it provides a quick and efficient means for retrieving old records in a form suitable for comparison.

(4) The collection and storage of data on magnetic tapes in a form suitable for direct input to high speed computers will make it convenient to perform adequate statistical studies on large quantities of data. The diagnosis of cardiac and circulatory conditions from an electrocardiogram is still largely empirical, and it appears desirable to set more accurate limits for normality and abnormality. There is a need to investigate new criteria for evaluating the data and to perform evaluation studies on the effectiveness of these criteria. The use of a digital computer provides a flexible tool for this purpose and provides a means of applying sophisticated mathematical techniques completely impractical by hand methods.

The raw data for this pilot study have been collected in Veterans Administration hospitals by recording electrocardiographic signals on magnetic tape. For this project, VA physicians have an electrode system such that three orthogonal signals are generated; these represent the three components of the heart vector. The method chosen for recording these signals was wide-deviation FM. A fourth channel using direct recording was reserved for voice identification of

the patient. The records for approximately 100 patients can be recorded on a single 12-inch reel. In this fashion large quantities of data from various field hospitals may be accumulated conveniently.

The conversion of the data into a form suitable for analysis by a digital computer is accomplished by a medical technician at a central processing installation for which the equipment herein described is a prototype. The data, as originally recorded, is continuous in nature. It is put into the desired digital form by sampling each of the three analog values at 1 msec intervals. Since it has been planned to make prototype studies at the National Bureau of Standards, where an IBM 704 computer is available, the format chosen was for this machine.

2.0 SYSTEM REQUIREMENTS

The central processing facility is designed to accept the original magnetic tape recordings and to produce another magnetic tape containing this information in the required numerical form. While the prototype facility was initially aimed at the electrocardiograph problem, it was expected that the number and kinds of information would increase. For this reason the equipment was designed to be expandable. Only three channels are presently used for ECG data, but provision has been made for increasing the number of channels by simply adding plug-in units. In order to maintain adequate fidelity for the digital electrocardiogram, an equivalent bandwidth of 0 to 200 cps is considered necessary. For this reason a sampling rate of 1,000 samples/sec was chosen so as to provide 5 samples per cycle at the highest frequency of interest.

Since it is expected that this equipment will be operated by a medical technician, it is imperative that the controls be kept simple and as few as possible. In addition they should be so designed as to minimize operator errors. Provision must also be made for correction of errors, if they do occur.

Means must be provided for selecting and monitoring one or more specific waveforms, from the 10-second sample usually taken from each patient. In addition, provision must be made for including calibration information on the original analog recording, as the raw data will be received from many sources. The accuracy requirements for medical data are generally in the order of a few percent. Conversion of analog data into 7 or 8 binary digits would generally suffice; however, since analysis will here require a certain amount of pattern recognition, it is felt that the resolution of the converted data should be somewhat better. For this reason, the ECG values are represented by 10 binary digits. In anticipation of adding other continuous variables, the format provides two bits in each word to identify the type of data the word contains. (See Appendix A.) Patient identification is inserted by manual setting of a 6-digit number.

3.0 OPERATING PROCEDURE

Figure 1 shows a block diagram of the equipment that has been designed and assembled for this purpose. The X, Y, Z components of the heart signal are re-played from the play back heads on the Analog Tape Recorder. The operator listens for the patient's identification number on the voice channel, and enters it on his Control Unit by positioning a 6-digit switch on the front panel of the latter. This Control Unit contains a high-speed 4-channel electronic switch which permits viewing the three components simultaneously on the Display oscilloscope. The three wave-forms viewed correspond to that portion of the sequence of heart cycles that will be numerically recorded if so ordered by the operator. This Unit also provides adjustments for selecting the beginning and end of the heart complex desired. This is easily done in a matter of seconds with the aid of the Display. When the operator has selected the stretch of wave-forms he wishes to digitize, he presses the "record" key on his Control Unit. The Tape Control, which receives the "start" signal produced thereby, brings the digital tape up to proper speed. After a few milliseconds delay, to produce proper gap lengths between recordings, a "run" signal is sent to the Format Control which drives the Digital Write Electronics in the Digital Tape Recorder.

The Format Control consists of a diode selector matrix sequenced by two ring counters and their associated clock circuitry. It is designed to accept parallel binary digits and deliver them serially on six parallel channels; a seventh channel is used for timing. This unit continues to operate as long as the "run" signal is applied. Since the Analog-Digital Converter is to be time-shared among three signals, an analog delay must be provided for two of these. All three are read simultaneously from the analog magnetic tape, and the X-signal is converted immediately. The Y signal is amplified and delayed 1/3 ms before it is presented to the A-D Converter. Similarly, the Z-amplifier is designed to delay the Z-signal for 2/3 ms. The counters in the Format Control provide control signals for the Multiplexer; this consists of a three-channel transistorized analog switch. The Multiplexer produces a trigger signal to initiate the operation of the A-D Converter, whose outputs are fed to a Buffer for driving the diode matrix, as they are switched from X to Y to Z. Figure 2 is a picture of the assembled equipment.

About 1,000 cardiac complexes of some 800 points each can thus be stored on one 2,400-foot reel of digital tape. Programs are being written for carrying out on the IBM 704 Computer the processing and printout of this digitized data, after collating it with patient histories fed from the Card Reader.

4.0 COMPONENTS

4.1 Analog Tape Recorder

This unit is a commercially available analog tape recorder, containing three wide-band FM channels for the ECG waveforms and

one direct recording channel for patient identification. On the FM channels it has a frequency range from dc to 2.5 kc at a tape speed of 15 ips. This unit has been modified slightly to provide an additional output by including an additional head connected to a fifth playback amplifier. Its position on the tape is several inches ahead of the normal read head, so that it produces a signal earlier in time; from this a sync pulse has been obtained for controlling the sweep circuits of the Display unit.

4.2 Operator's Control Unit and Display

Figure 3 shows the circuitry of the Operator's Control Unit. The input signals are X, Y, Z, trigger, and voice from the analog tape unit. The inputs X, Y, and Z are fed into Amp 2, Amp 3, and Amp 4, which are Type K2W, as shown on Figure 3a. These amplifiers provide a gain of 7, thus producing an output of 10 volts for approximately 1.5 volts input. The 10-volt level is full scale for the A-D converter. Amplifiers, 3 and 4 are designed (see Appendix B) to delay their input signals to allow time for conversion. All three outputs appear at output connectors from which they are cabled to the multiplexer. They are also fed to drivers D4 and D5 which feed an electronic switch for display purposes. Centering controls are provided for each of the signals; this is done by shifting the d-c output levels of D4 and D5. There are four channels available in the electronic switch, but one has been suppressed. Each signal is fed to the collector of a gating transistor. The emitters of the three transistors are paralleled and provide the vertical deflection of the Display scope.

Only one transistor at a time is turned on. The gating of the transistors is sequenced as follows. A free-running multivibrator MV-1 oscillates at about 20 kc. Its output is fed to a bi-stable flip-flop CFF-1 which divides the frequency by two. The outputs of MV-1 and CFF-1 are fed to drivers D6 and D7. Since each of the two units may be in two possible states, there are four combinations possible altogether. The outputs of the drivers feed and-gates which select the four possible conditions, and the outputs of the and-gates are used to turn on the transistorized electronic switch. Each time MV-1 changes states, a positive pulse is produced by the bridge circuit made up by CR 9, 10, 11, 12. These pulses are used to blank the display during the switching time from one channel to the next.

The input $TRIG_{in}$ is fed into amplifier AMP1. This signal comes from the analog tape unit and is generated from the X channel by the extra head which is several inches ahead of the "read" head. It therefore occurs earlier in time, but is similar in form to the X component of the heart vector. The output of AMP1 drives a Schmitt trigger (TRIG 1). This circuit changes state each time its input signal exceeds a fixed level and returns to its original state when the input signal falls below this fixed level. An indicator is provided on the front panel to indicate whether or not the circuit is triggering. A sensitivity control is provided for the operator so that he can adjust the triggering level for optimum. The output of the trigger is sent to DMV1. This

delay is also variable and under control of R2.

The sweep signal for the Display is derived from the internal timing mechanism of DMV2 and buffered by driver D2. By adjusting R2, the turn-on time of DMV2 is set to occur just ahead of the electrocardiogram, and by adjusting R3, DMV2 is set to turn off just after its completion. The output of DMV2 is used to gate the recording cycle, so that the operator can see exactly what is being recorded. That is accomplished by feeding the output of DMV2 via driver D3 to one input of a 2-input and-gate consisting of CR 13, and CR 14. The other input to the and-gate is supplied by flip-flop DFF2. The output of the and-gate is buffered by driver D3 and fed to flip-flop DFF1. The output of DFF1 produces the start/stop signal for the system. DFF1 can only be triggered by the leading edge of the output of DMV2 if DFF2 has been set by the "record" key. Thus, if the "record" key is operated during a display, DFF1 will not be energized until the start of the following display, thereby preventing the recording of partial complexes.

The and-gate behaves as an "or" for negative signals so that DFF1 is always reset at the trailing edge of the output of DMV2, whether DFF2 is set or not. At the end of a recording cycle the trailing edge of the output of DFF1 is used to reset DFF2. A "ready" light and "record" light are provided on the front panel to indicate the status of these two flip-flops. The detailed circuitry of the various plug-in units is shown in Figures 3b, 3c, ... 3g.

This Control Unit also contains provisions for patient identification by manually setting a 6-digit number on panel switches. Their arrangement is shown in Figure 4. Each switch provides 1-2-4-8 BCD code representing digits from zero to nine. In addition, provision is made for deleting records, tagging calibration records and for putting a "logical tape end" signal on the digital tape after the last recording has been made. The details of thie circuitry are shown in Figure 4.

The voice signal from the Analog Tape Recorder is fed into an audio amplifier and speaker so that the operator may hear the physician's spoken identification of the patient. In addition, a monitoring signal from the Digital Tape Recorder is fed through a pre-amplifier and limiter to the audio amplifier (Figures 5 and 6). It is helpful to be able to monitor the digital tape, as a means of locating the last digital record of a previous recording session, and as an indication that a normal recording is being made.

4.3 Tape Control

Figure 7 is a block diagram of the Tape Control. The sequence of operations is initiated by a positive pulse at the EXT START terminal. This signal actuates delay multivibrator DMV1. The output of DMV1 is fed to or-gate OR 1 which in turn energizes amplifier AMP 1 and delay multi-vibrator DMV2. The output of AMP 1 provides a signal which causes the digital tape transport to start moving

tape. AMP 1 also provides a pulse which is fed to the head driver flip-flops. The output of DMV2 provides a signal turning on these flip-flops in preparation for making a recording. It must be noted that DMV2 is direct-coupled in such a way that a delay occurs only for the turn-off signal, and <u>not</u> for the turn-on signal.

Since the PRESET signal and the HEAD CURRENT GATE signal occur simultaneously, the head driver flip-flops are set to their reference direction. When DMV1 returns to its initial state, after the few milliseconds delay necessary to get the tape up to speed, and to provide proper gap lengths on the tape, a pulse coincident with the trailing edge of its output is fed to flip-flop FF1 causing it to change state. The output of FF1 and DMV1 are both fed to an and-gate in the Format Control. The output of this and-gate controls the operation of this unit. The Format Control will operate as long as any of its four inputs to the and-gate are "down". Thus, operation starts with the trailing edge of DMV1 and will be kept running by FF1. The output of this and-gate is inverted by INV1 and is then fed to or-gate OR1 to keep the tape running and maintain the HEAD CURRENT GATES on. A recording cycle is ended by applying a negative pulse to the EXT STOP terminal.

This signal resets FF1 to its initial state. The Format Control will then complete its scan when the WORD COUNTER and CHARACTER COUNTER return to their initial positions, and the output of the and-gate will rise. This signal is then inverted by INV1 and causes the output of or-gate 1 to fall. INV1 also produces a pulse at this time which is delayed by DMV3 and is used to reset the head driver flip-flops to the reference state. This is necessary to maintain clean tape gaps between recordings. When the output of or-gate 1 falls, AMP1 causes the tape transport to shut off. Head current is maintained for a few milliseconds by the action of DMV2 until all motion of the tape has ceased. This too is a precaution to keep the tape gaps clean.

Detailed circuitry is shown in Figures 8 and 9.

4.4 Format Control

The Format Control is effectively a 64-position 6-pole commutator switch, as shown in Figure 10. Of the possible 384 possible lines to the diode matrix, only 8x36 are needed to supply the six output channels. The commutator sequentially connects all six outputs to successive groups of six inputs. The data on any one output channel consists of 48 bits per scan, one for each of six characters in each of eight words. Details of the various circuits are discussed below.

4.4.1 Diode Matrix.

The cross-bar switching arrangement shown schematically in Figure 11 is made up of a number of and- and or- gates. The input gates are supplied by static voltages (either 0 or +20 v). Data

appearing at the output of channel 1 are received from the input lines connected to the first and-gate in each of the rows and columns of the matrix. Character drivers supply positive-polarity pulses to all eight gates in a particular column, and word drivers supply positive-polarity pulses to all eight gates in a particular row. The first character in the first word is selected by the simultaneous occurrence of a pulse in the character column 1 and in row 1. The second character in the first word is selected by the coincidence of a pulse in column 2 and in row 1. The character driver pulses are advanced from column 1 to column 6 in sequence and then returned to character number 1; the word "read-out" pulses are advanced from word position 1 to word position 8. This cross-bar selection continues until all 48 characters in the matrix have been read out.

The sequence of operations is started by introducing a negative pulse from the Tape Control into the time-base generator and clock control. This input is one of four to an and-gate. When the and-gate is "up" (this requires coincidence of all four inputs), it inhibits the operation of the time-base generator. Before the "start" pulse is introduced, both counters are in their "1" position. The and-gate goes "down" with the negative-going "start" pulse, allowing the time-base generator to operate. The time-base generator is held in operation by a flip-flop in the Tape Control which is set by the "start" pulse. The output pulses from the time-base generator drive a dual delay multivibrator whose purpose is to produce pulses of proper width and amplitude. The output of the first half of the dual delay multivibrator provides the necessary time for triggering the A-D Converter, making a conversion, and setting up the numerical value in the Buffer. The output of the second half serves the following three functions :

(1) It produces an output on the six information channels by energizing the output and-gates preceding the line drivers (see Figure 11). The first read-out corresponds to the first character of the first word, since the counters are in these states at the start.

(2) It provides the output on the seventh or sprocket channel.

(3) The trailing edge of the pulse operates the character multivibrator which advances the character ring-counter.

Each output pulse connects the six output channels to successive 6-bit characters in the diode matrix, the character counter being advanced at the end of each character readout. When the character counter goes through a complete cycle and returns to the "1" position, it provides a signal which energizes the word multivibrator which then advances the word ring-counter. This sequence of operations continues until a stop signal originating in the operator's Control Unit resets the clock control flip-flop in the Tape Control. However, the clock control will continue to operate until the word and character counters return to their initial positions, causing the and-gate to come "up". Thus, each recording must consist of an integral number of 8-word blocks.

4.4.2 Ring Counters

Figure 12 shows a schematic diagram of the "magnetron" beam switching tube used as a counter for characters or words. This tube is capable of maintaining a beam of current on any one of the 10 targets arranged in a ring. It can be switched from one target to the next by driving alternate grids with a push-pull voltage from the plates of a conventional flip-flop circuit. Since only eight positions are needed for the word counter, two targets have been eliminated by electrically preventing the beam from forming on them. The character counter is constrained to six positions. The potential at any target is approximately 250 volts when off, since there is no target current, and is approximately 120 volts when on.

4.4.3 Bi-Stable Multivibrator

Figure 13 shows the schematic diagram of the multivibrators MV1 and MV2 used to advance the character and word counters, respectively. They are conventional flip-flops in which only one or the other tube is permitted to conduct. Each input pulse causes both tubes to change states. The outputs are taken from the plates and are fed to the grids of the ring counter tubes. The character multivibrator is triggered by the trailing edge of the delay multivibrator output pulse, and the word multivibrator is triggered by the negative pulse at the No.1 target of the character ring counter when it returns to the No. 1 position.

4.4.4 Dual Delay Multivibrator

Figure 14 shows the schematic diagram of the dual delay multivibrator DMV1 and DMV2. Input trigger pulses from the time base generator produce standardized output pulses. The second DMV is triggered by the trailing edge of the first DMV. The cathode follower outputs provide the necessary power for operating the associated circuits.

4.4.5 Time-Base Generator and Clock Control

Figure 15 shows the schematic diagram of this unit. The circuit consists of a blocking oscillator which is turned on or off by the output of a four-input and-gate. When all three inputs are "up" (+20v), the common cathode is also "up". This bias is sufficient to keep the blocking oscillator from operating. When any of the three inputs is "down" (0 volts), the blocking oscillator becomes free-running, producing negative pulses at a frequency determined by the time constant in the transformer secondary.

4.4.6 Character and Word Drivers

There are eight character drivers and eight word drivers, all identical, in the Format Control. Their purpose is to energize with the proper wave-form the proper row and column in the diode matrix. Figure 16 shows the schematic diagram of one such driver. Its input is

obtained from a target of one of the ring counters. When this target is "off" the net voltage to the input transistor is positive. The input transistor operates as an emitter-follower; its output is positive and of sufficient magnitude to turn the output transistor "on". The output is then held at ground potential. When the counter advances to an "on" position, the input voltage falls and the net voltage to the input transistor is negative. This negative voltage also appears at the output of the emitter-follower and is sufficient to cut off the output transistor. The collector voltage will then rise until it is limited by the diode at +20 volts. This arrangement is capable of handling large signal currents with little power dissipation in the output transistor. When the output is "down", the output voltage is approximately 0.4 volt, and at 100 ma load current the dissipation is only 40 mw. When the output is "up" (+20v), all the load current is carried by the bumper diode at a dissipation which is again small because of the small forward drop of this diode.

4.4.7 Line Driver

Figure 17 shows the schematic of the output-line driver used in the Format Control. It is a dual cathode follower whose purpose is simply to shift the d-c level of the output pulses and to provide the required power level for properly driving the associated equipment.

4.4.8 Beam-Former

When the Format Control is initially turned on, it is possible to find one or both of the counter tubes in the "cut-off" condition. The automatic beam-former, shown schematically in Figure 18, senses the presence or absence of cathode current in the counter tubes. If one or both are "off" it energizes the relay. When the relay closes, its contacts ground the "1" spade of each counter. This causes each to form a beam on its "1" target As soon as the beams are formed, the relay is automatically de-energized and the counters resume normal operation.

5.0 DIGITAL TAPE RECORDER

The digital tape transport is a commercially available 7-channel magnetic tape transport using 1/2-inch tape. A detailed description can be obtained from the Ampex Corporation on the Model FR 200. To summarize, it contains the following three major subassemblies:

5.1 Tape Drive Assembly

This portion is responsible for proper motion of the tape. It consists of a drive motor, capstan, and pinch rollers with their associated solenoids.

5.2 Tape Tension and Servo Control Assembly

This mechanism is used to maintain constant tape tension during operation of the transport. It consists of two take-up arms, the take-up and supply motors, with a switching arrangement and associated circuitry, which provides the servo control function.

5.3 Control Circuit Assembly

This provides proper switching and interlocks for turning power on and off, forward and reverse run, and manual playback. It also provides the necessary solenoid amplifiers through which the tape transport can be controlled either manually or electronically.

6.0 DIGITAL "WRITE" ELECTRONICS

The "write" electronics consists of seven transistorized flip-flops capable of supplying enough magnetizing current to the "write" heads to fully saturate the magnetic tape. The "write" heads are center-tapped and are connected to the collectors of the transistors so that approximately 30 ma flow in one or the other half of the winding, depending on which half of the flip-flop is conducting. Figure 19 is a schematic diagram of one of the head drivers. A transistor gate is used so that head current can be turned on and off as needed. Head current is allowed to flow only while writing; this precaution is necessary to prevent inadvertent erasure of a previous record.

To insure that head current flows in the reference direction when the "write" gate is energized, a "preset" signal is used. This signal is a positive pulse fed to the flip-flop through its associated diode which causes the flip-flop to start always in the reference direction. After the "write" gate is energized, the flip-flop will accept inputs from the Format Control. Steering diodes are used to couple these signals to the bases of the flip-flop, causing them to change state for each successive input pulse. In order to maintain the magnetic tape reference level in the gaps between blocks of information, a "reset" signal is provided at the end of each block of information which causes the flip-flops to return to the reference state.

7.0 MULTIPLEXER

The Multiplexer (presently three-channel) consists of several plug-in units, one for each information channel and one additional unit for generating a trigger to initiate the operation of the Analog-to-Digital Converter. Figure 20 is a schematic of one analog-gate plug-in unit. CR1 and CR2 are used to provide a two-input and-gate in conjunction with pull-up resistor R1. The output of this and-gate is fed through CR3 to the trigger generator (Pin 1, Fig. 21). Thus CR3 and the corresponding diodes of other plug-in units form an or-gate feeding the trigger unit in conjunction with the pull-down resistor R1 of the trigger generator. The output of the and-gate is amplified and inverted by T1 which then turns on T2. Thus, the collector of T2 approaches

the emitter voltage of +10 volts whenever both inputs to the and-gate are present. The emitters of all the analog-gate plug-in units are tied together to form an output line. Thus, any information channel may be selected to appear on the output line by properly energizing its associated gating circuitey. The signals for energizing those gates are generated by the character and word drivers, as described under Format Control.

The output of the or-gate feeds one input of a two-input and-gate consisting of CR1 and CR2 in the trigger generator (Fig. 21). The second input is a narrow pulse which occurs at the clock rate of the Format Control. The output of this gate is amplified by T1 and inverted by T2 to provide the trigger signal for the A-D Converter. Thus, for each channel of information a trigger is generated at the proper time. The capacity of this unit can, therefore, be increased or decreased simply by adding or removing analog-gate plug-in units.

8.0 ANALOG-DIGITAL CONVERTER

The A-D Converter is a commercially available unit capable of making 45,000 independent analog-to-digital conversions per second. Each conversion produces ten binary bits plus sign to represent the input analog value. For details of this unit, the instruction manual for the DATRAC Model B-611 of EPSCO, Inc. should be consulted.

9.0 BUFFER

The Buffer consists of plug-in transistorized amplifiers which accept the outputs of the A-D Converter and provide the necessary power for driving the Format Control. Figure 22 is a schematic of one of the plug-in units. Each unit contains two amplifiers. The A-D converter produces a -20v signal for a binary "one" and Ov for a "zero." When a "one" is fed to the input of the amplifier the transistor is turned "On" producing a +20v at the output. When a "zero" is applied, the transistor is held off, and the 33k pull-down resistor tied to -150v causes the output to go negative. However, the output is held at 0 volts by bumper diodes 1N67 connecting the collectors to ground. Thus, the signals are inverted to make them compatible with the Format Control, as well as amplified. In order to keep the polarity of the sign bit the same as in the IBM 704, an inverter circuit (Figure 24) has been provided for the sign channel.

10.0 PROGRAMMING AND DATA CORRELATION

In order to use the digitalized data for statistical studies, the Veterans Administration plans to complement the ECG information by additional historical and clinical information about the patient. This will be done by entering data such as name, sex, age, height, weight, record of illnesses, and clinical findings on an IBM punched card, or cards, together with patient identification number as recorded on the digital magnetic tape. In cases where more than one recording of a patient has been made, the cards will carry the additional record

numbers and their associated dates. Studies may then be made based on age groups, weight groups, etc. or combinations of these parameters, by merging the tape and card information. Whenever additional data is acquired or computed the new information may be added to the punch card under computer control. To improve computer access time, this card information could be stored on another magnetic tape. The punched cards may also carry the information in printed form. These cards may be kept in numerical, or alphabetical order for the purpose of maintaining readable records. Another advantage of keeping the records in this form is the availability of equipment for sorting and collating the information rapidly and automatically.

The program will also include provision for calculating the proper calibrations for the digitized electrocardiogram. At each station where data is collected a 10 cps 2 mv peak-to-peak square wave will be recorded on the analog magnetic tape. During playback at the central processing installation, this is noted by the operator who then tags the record with the special code for calibration (see Appendix A - Data Format). When the data is read into the digital computer the calibration code causes it to calculate the calibration constant for each channel which it then applies to all succeeding data until a new calibration is noted.

The digital program will also contain a subroutine for discarding any record which is followed by a record marked with a "delete" code. This provides the operator with a means of eliminating records which are improperly made as a result of a poor analog record or a manual error.

11. ACKNOWLEDGEMENTS

Acknowledgement is due to Dr. Hubert V. Pipberger of the Veterans Administration Hospital, Washington, D. C., for inspiring and supporting this program, and to Dr. H. L. Mason of the National Bureau of Standards who gave much of his time throughout the project. The author is also indebted to John Marlin, Thomas Childs, and Thomas Nolan of NBS for their contributions during the construction and checkout phases of the equipment.

In order to test the effectiveness of the overall scheme, a program for the IBM 704 computer was prepared by Mrs. Ethel Marden of NBS. This program provided a printout of the numerical data from which plots could be made. When this plot was compared with an enlarged photograph of the original data, it was found to overlap within the line width of the original recording.

Machine programs for statistical studies based on experimental diagnostic techniques are being prepared by Dr. R. J. Arms of NBS.

APPENDIX A

DATA FORMAT - FIGURE 23

To provide a means for keeping track of patients in a large statistical study, it was decided to provide a six-digit patient identification number. Each decimal digit is represented in 1-2-4-8 binary coded decimal (BCD) notation which uses four bits in each of six words, as shown in Figure 23. However, when BCD representations for the numbers 10 to 15 appear in these cells, they serve to tag the word with "Calibration", "Delete block" and "Tape end" markers. In addition, a two-bit code is recorded in bits 34, 35 of each word to identify the type of information it contains. This is necessary since four kinds of data will be included in future work:

(1) Electrocardiogram
(2) Ballistocardiogram
(3) Phonocardiogram
(4) Arterial Pressure

The location of these types of information within the block will depend on the sampling rates required. If a recording rate of 2,000 words per second is assumed, and the respective requirements are for (1) ECG at 1,000/sec, (2) ballistogram at 500/sec, (3) phonocardiogram at 250/sec, and (4) arterial pressure at 250/sec, the 8-word block might take the following form:

1st word	Electrocardiogram
2nd word	Arterial Pressure
3rd word	Electrocardiogram
4th word	Ballistocardiogram
5th word	Electrocardiogram
6th word	Phonocardiogram
7th word	Electrocardiogram
8th word	Ballistocardiogram

APPENDIX B

Design of Delays in Y and Z Amplifiers

In order to provide signal delay in the Y and Z amplifiers, a network has been synthesized to approximate e^{-2Ts} as follows:

$$e^{-2Ts} = \frac{e^{-Ts}}{e^{+Ts}} = \frac{1 - Ts + T^2 s^2/2 \ldots\ldots}{1 + Ts + T^2 s^2/2 \ldots\ldots}$$

As an approximation only the first two terms of the series are used. The operational amplifier of Figure 24 has the following transfer function:

$$e_o = \frac{R_f(R_1 + R_2)}{R_1 + R_2} + 1 \quad e_1 - \frac{R_f}{R_1} e_2$$

Simplifying

$$e_o = \frac{R_f}{R_1} \quad \frac{R_1 + R_2 + R_1 R_2/R_f}{R_2} \quad e_1 - e_2$$

Then letting $\frac{R_f}{R_1} = a$ and $R_2 = \frac{aR_1}{a - 1}$, we have

$$e_o = a \quad 2e_1 - e_2$$

By modifying input e_1 of Figure 24 by an RC network as shown in Figure 25, with

$RC = T$, $e_2 = e_1$, we have

$$e_o = a \frac{1 - Ts}{1 + Ts} e_1$$

For gain of 7, R_f is chosen = 700 Kohms

R_1 = 100 Kohms

$$\therefore \quad R_2 = \frac{7}{6} \times 100\,\text{k} = 116.7 \text{ Kohms}$$

Thus, the overall transfer function of the amplifiers AMP 2 and AMP 3 provides a flat amplitude response with a delay equal to 2T. By choosing the proper values of R and C the required delay in each channel is obtained.

At a delay of 2/3 ms (required in the Z channel) this network is within 5% accuracy out of 200 cps. For the Y channel where the delay required is only 1/3 ms, the network is within 5% out to 400 cps.

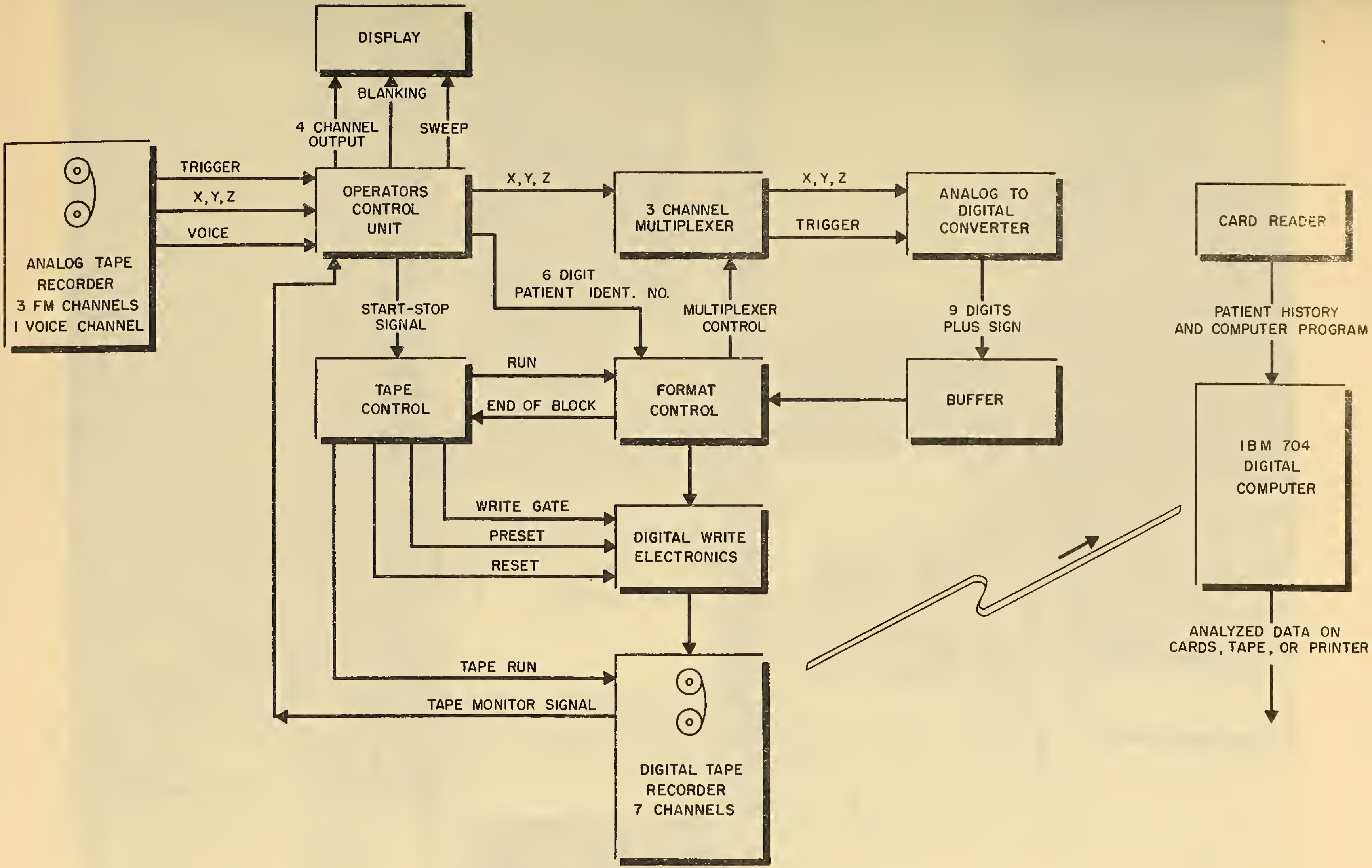


FIGURE I. OVERALL BLOCK DIAGRAM.

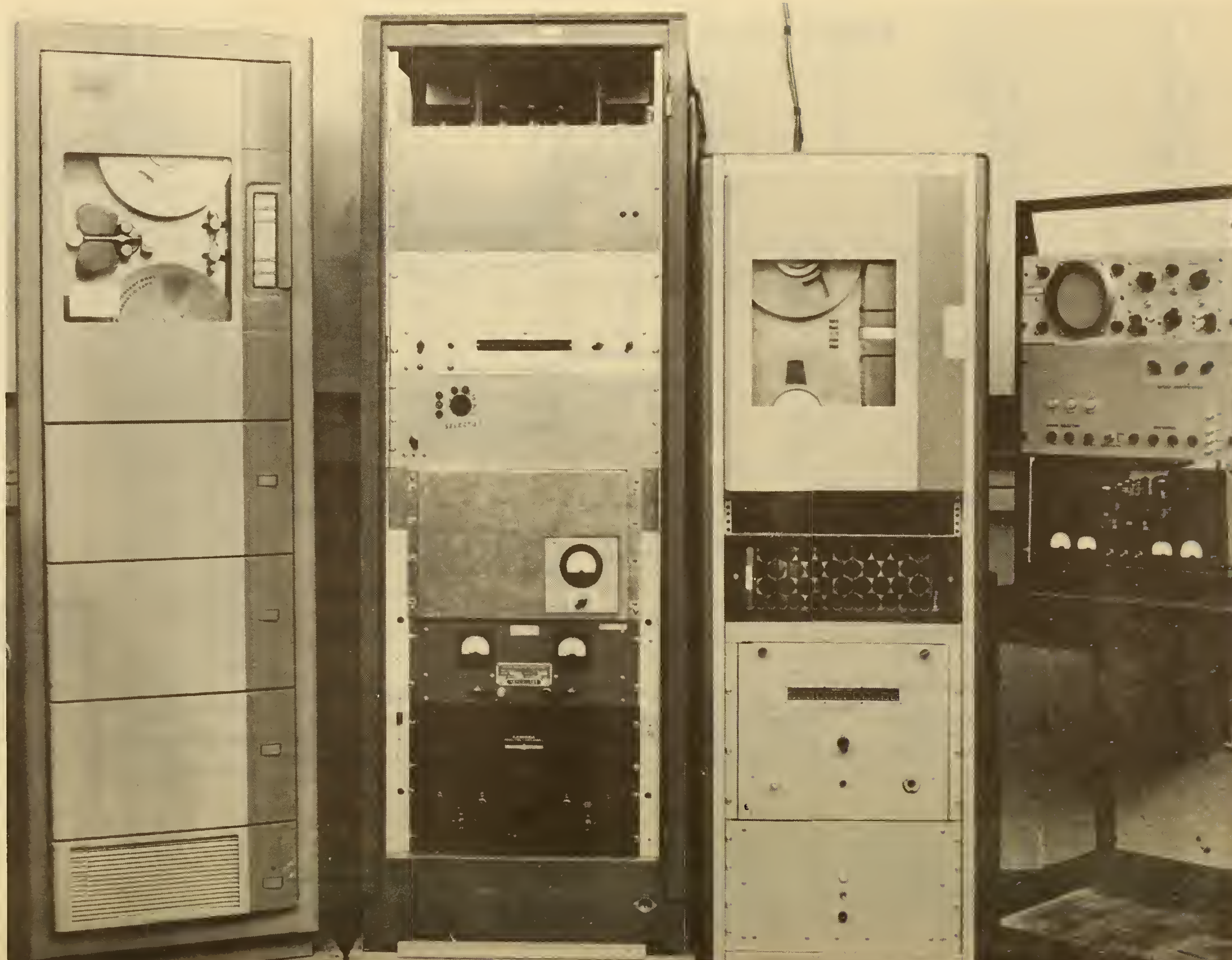


FIGURE 2. ASSEMBLED EQUIPMENT

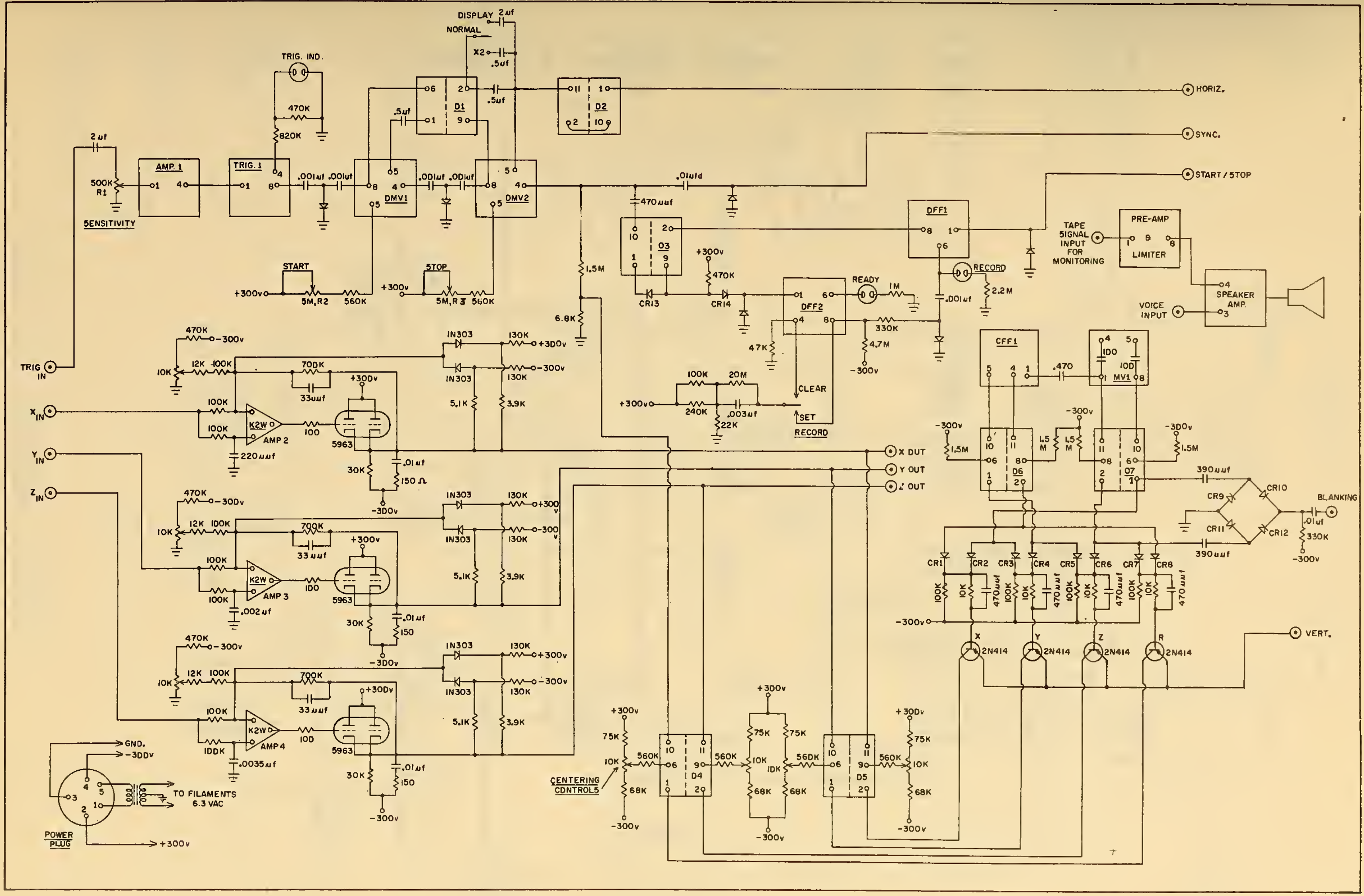


FIGURE. 3. OPERATORS CONTROL UNIT.

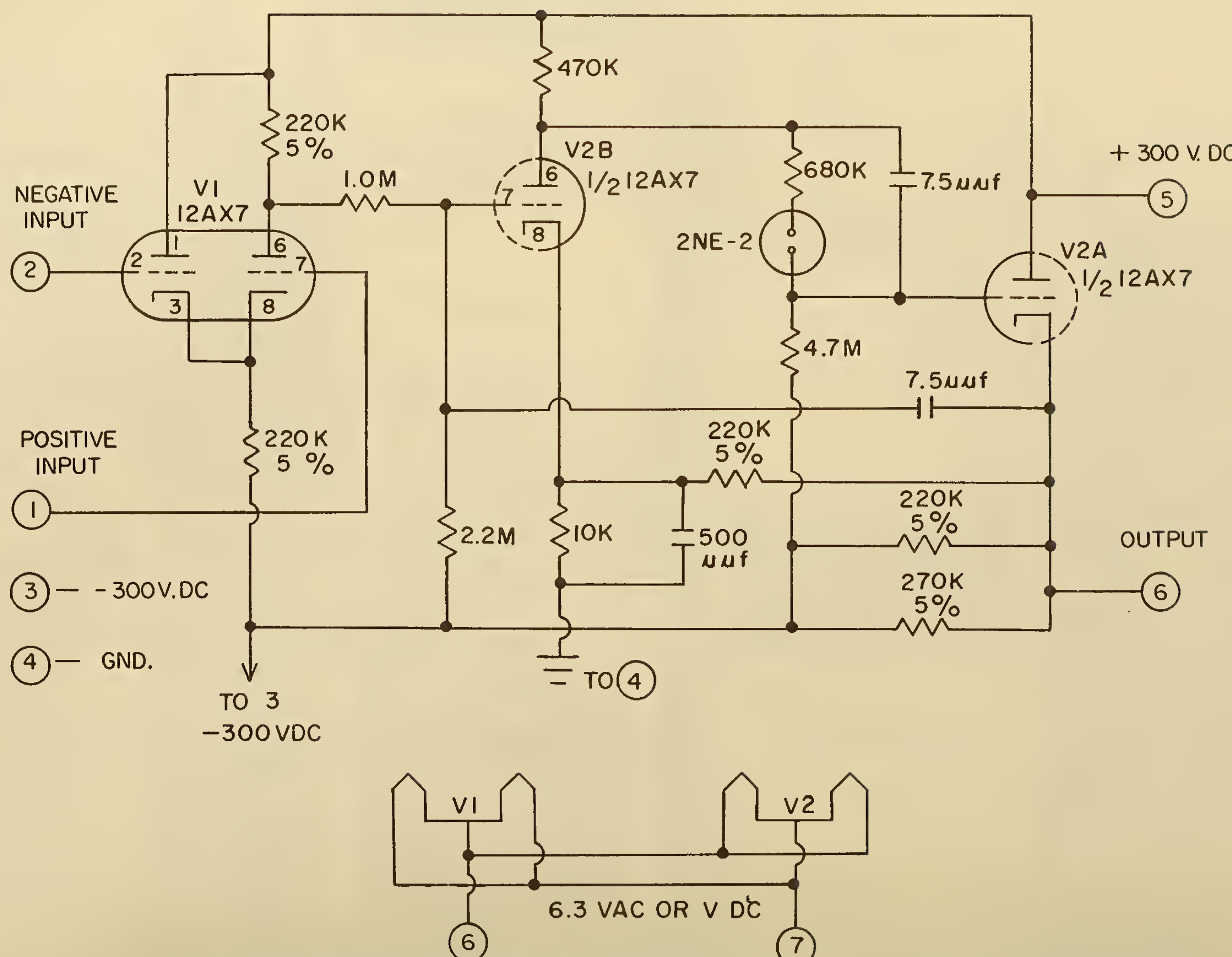


FIGURE 3 a. AMPLIFIER (K2W)

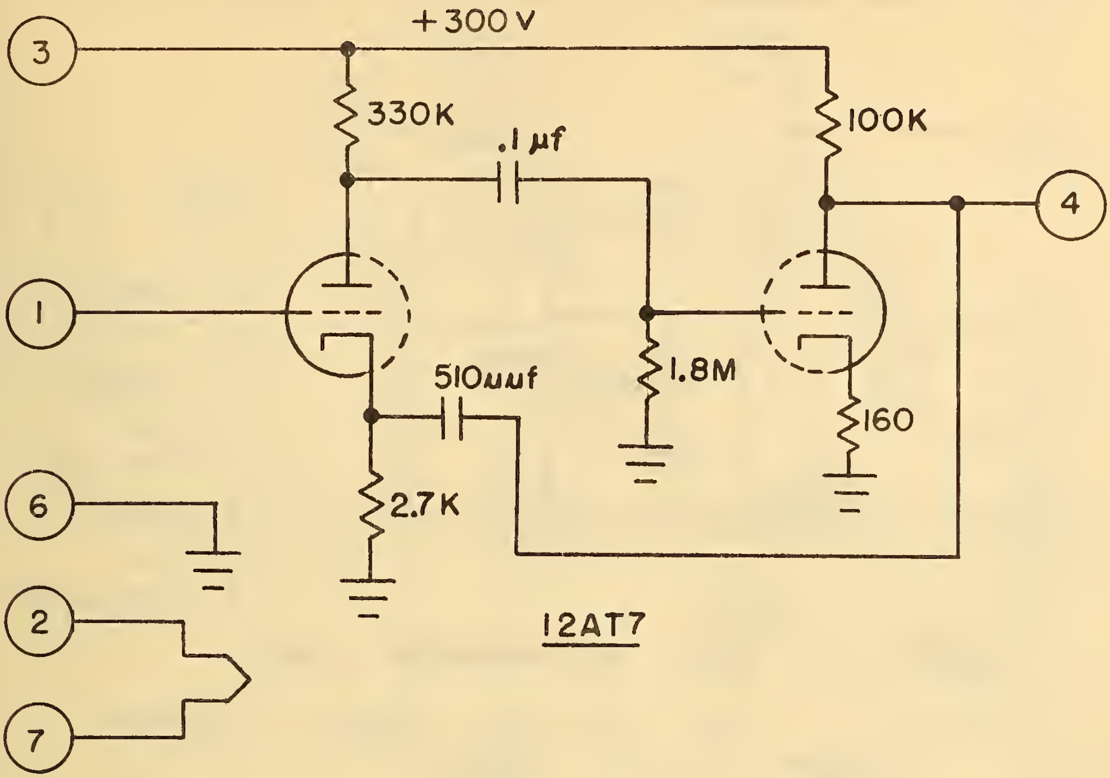


FIGURE 3 b. AMPLIFIER (AMP I)

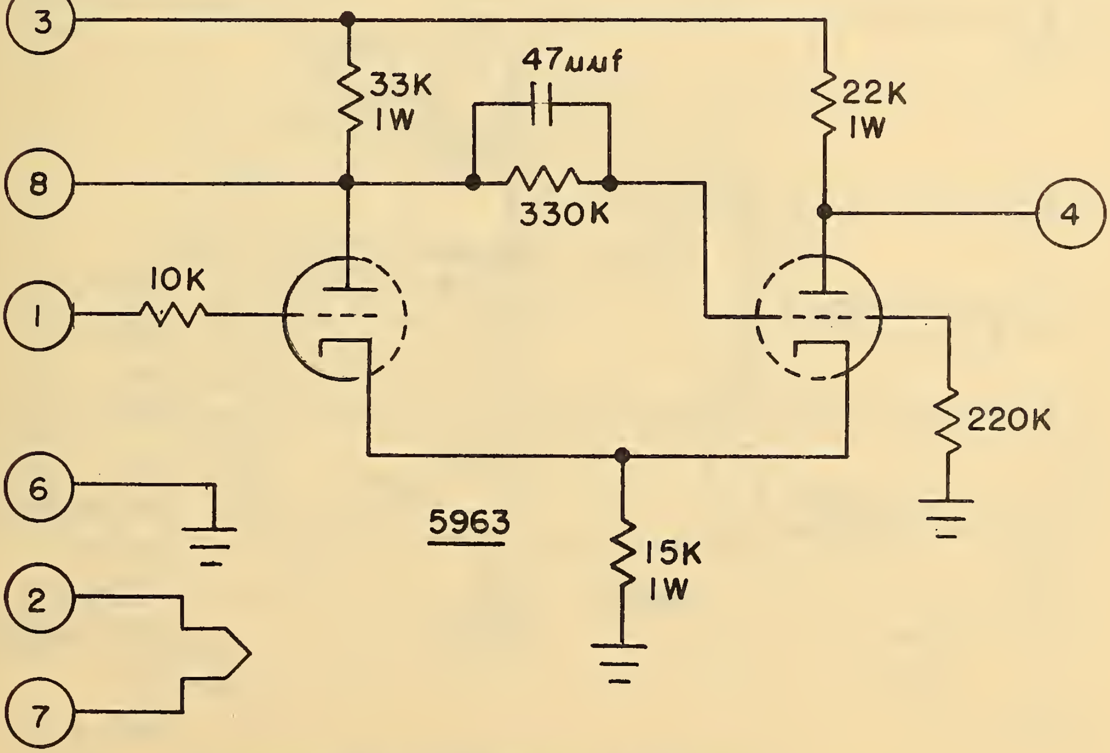
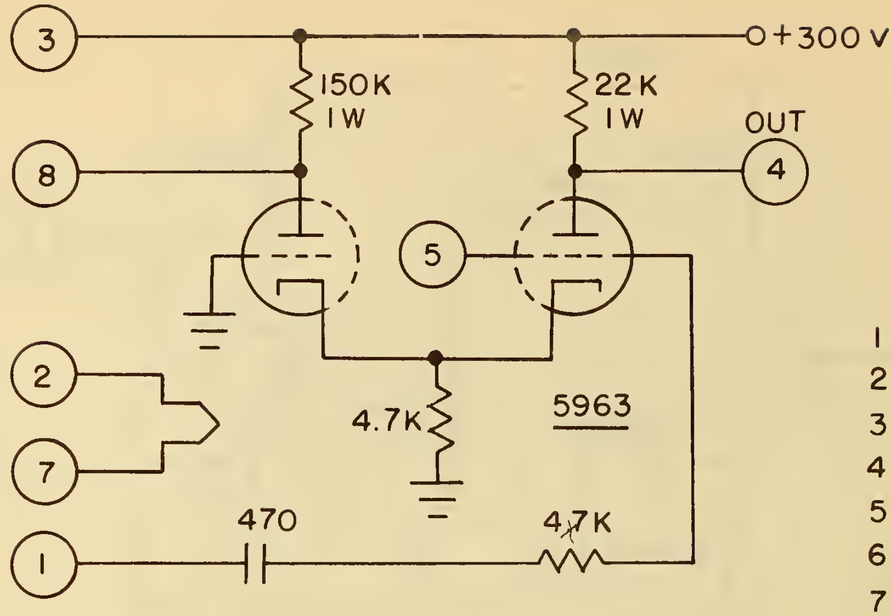
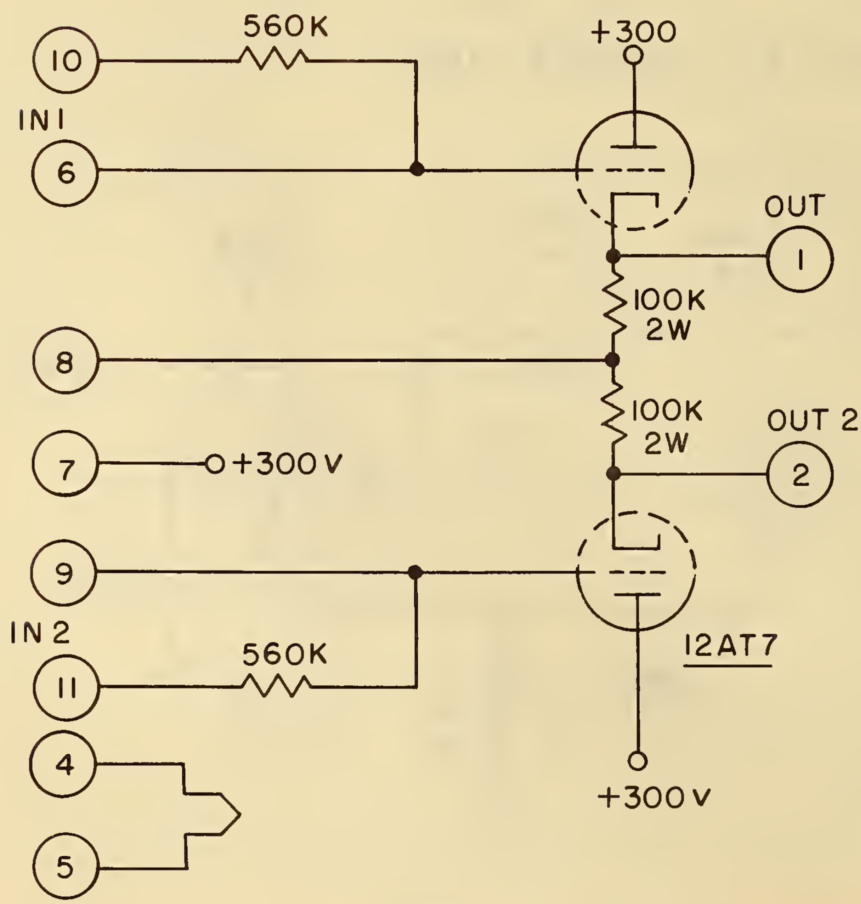


FIGURE 3 C. TRIGGER (TRIG)



1 - INPUT
2 - FIL
3 - +300 V
4 - OUT
5 - EXT. CAP.
6 - GND.
7 - FIL
8 - EXT. CAP.

FIGURE 3 d. DELAY MULTIVIBRATOR (DMV)



1 - OUT 1
2 - OUT 2
3 - GND.
4 - FIL
5 - FIL
6 - IN 1 (DIRECT)
7 - +300 V
8 - −300 V
9 - IN 2 (DIRECT)
10 - IN 1
11 - IN 2

FIGURE 3 e. DRIVER (D)

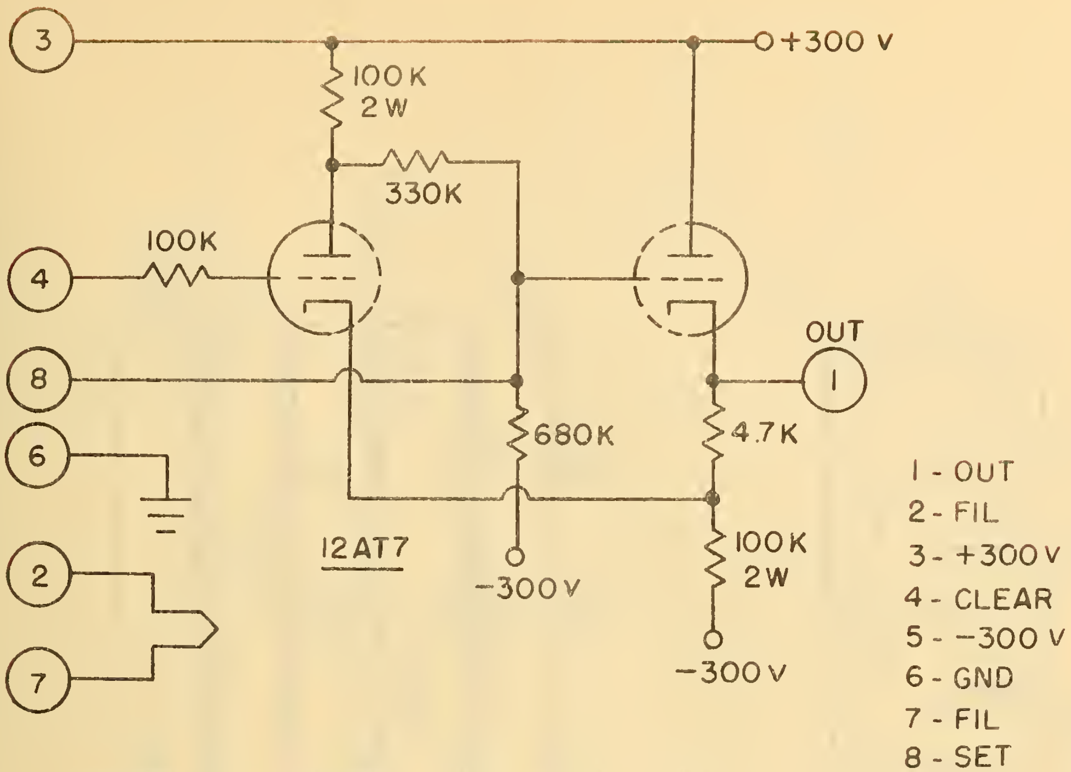


FIGURE 3 f. DRIVER FLIP-FLOP (DFF)

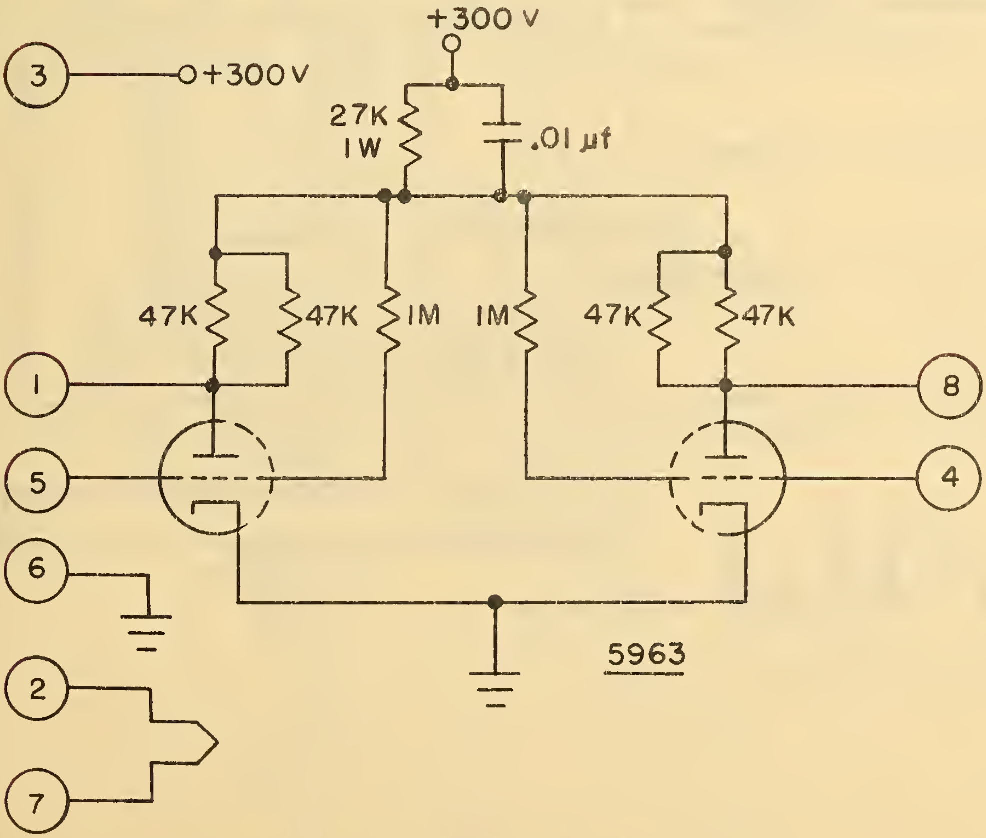


FIGURE 3 g. MULTIVIBRATOR (MV)

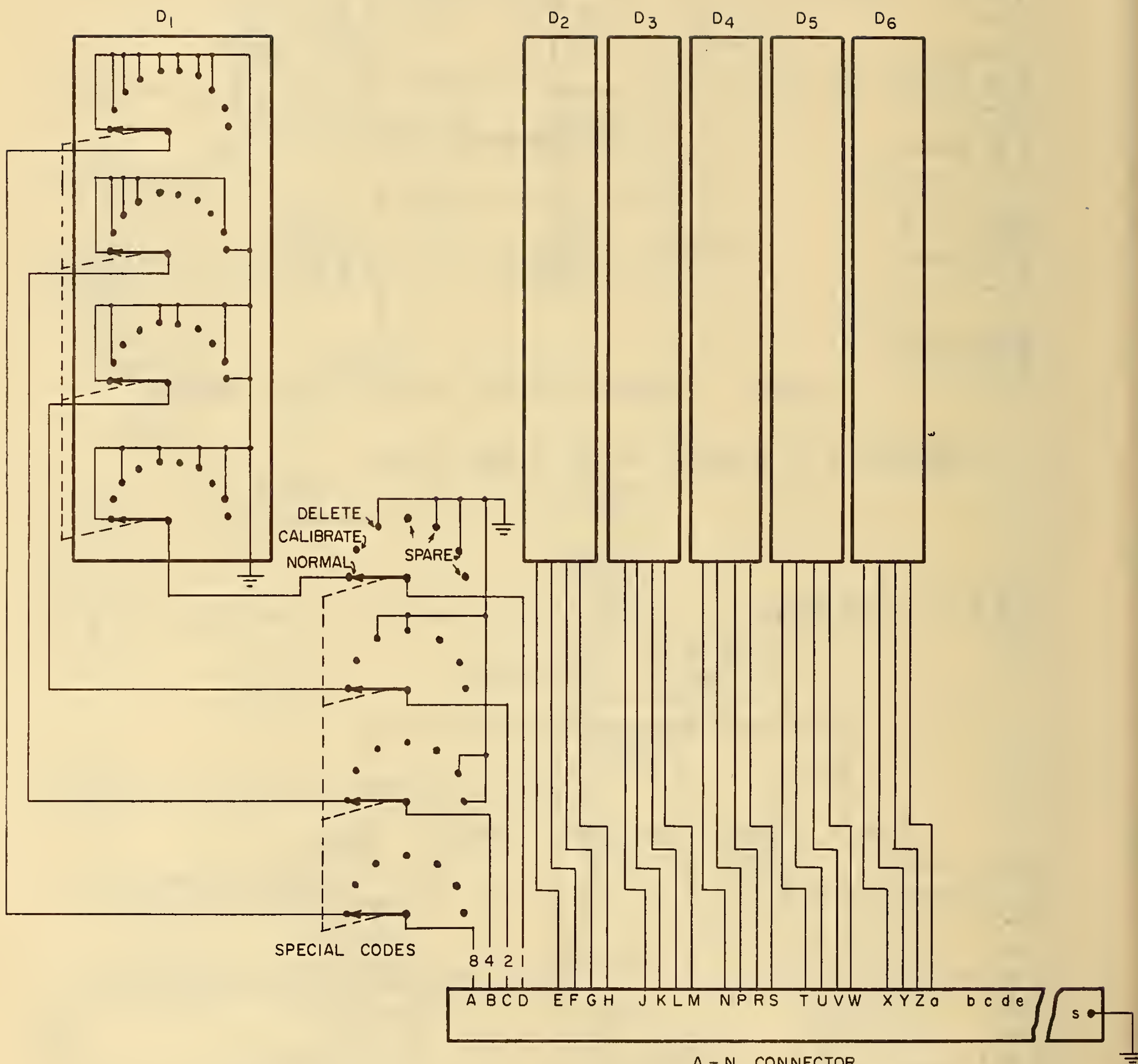
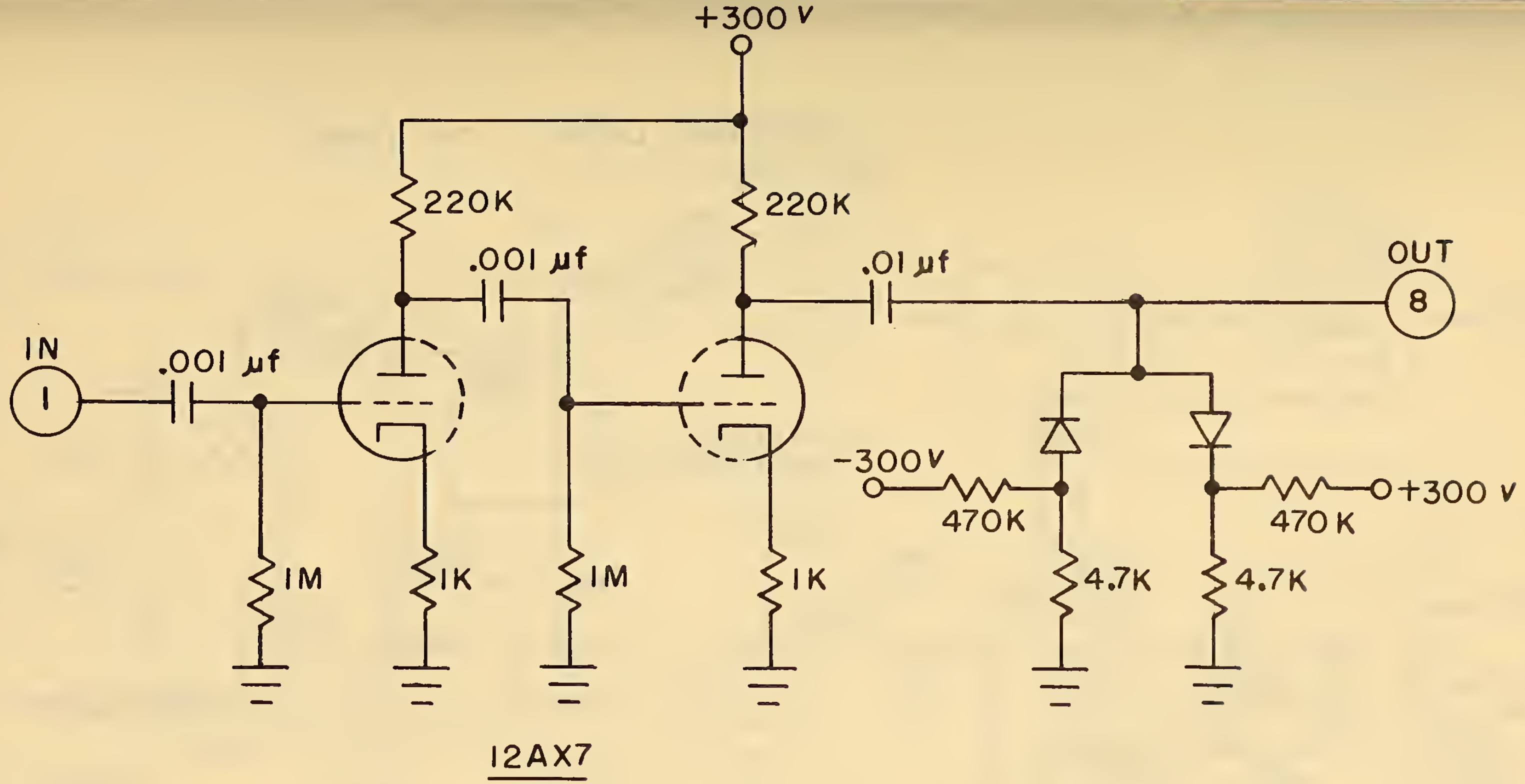


FIGURE 4. PATIENT IDENTIFICATION SWITCH



1 - INPUT
2 - FIL
3 - +300 V
4 - SPARE
5 - −300 V
6 - GND
7 - FIL
8 - OUT

FIGURE 5. PRE – AMPLIFIER AND LIMITER

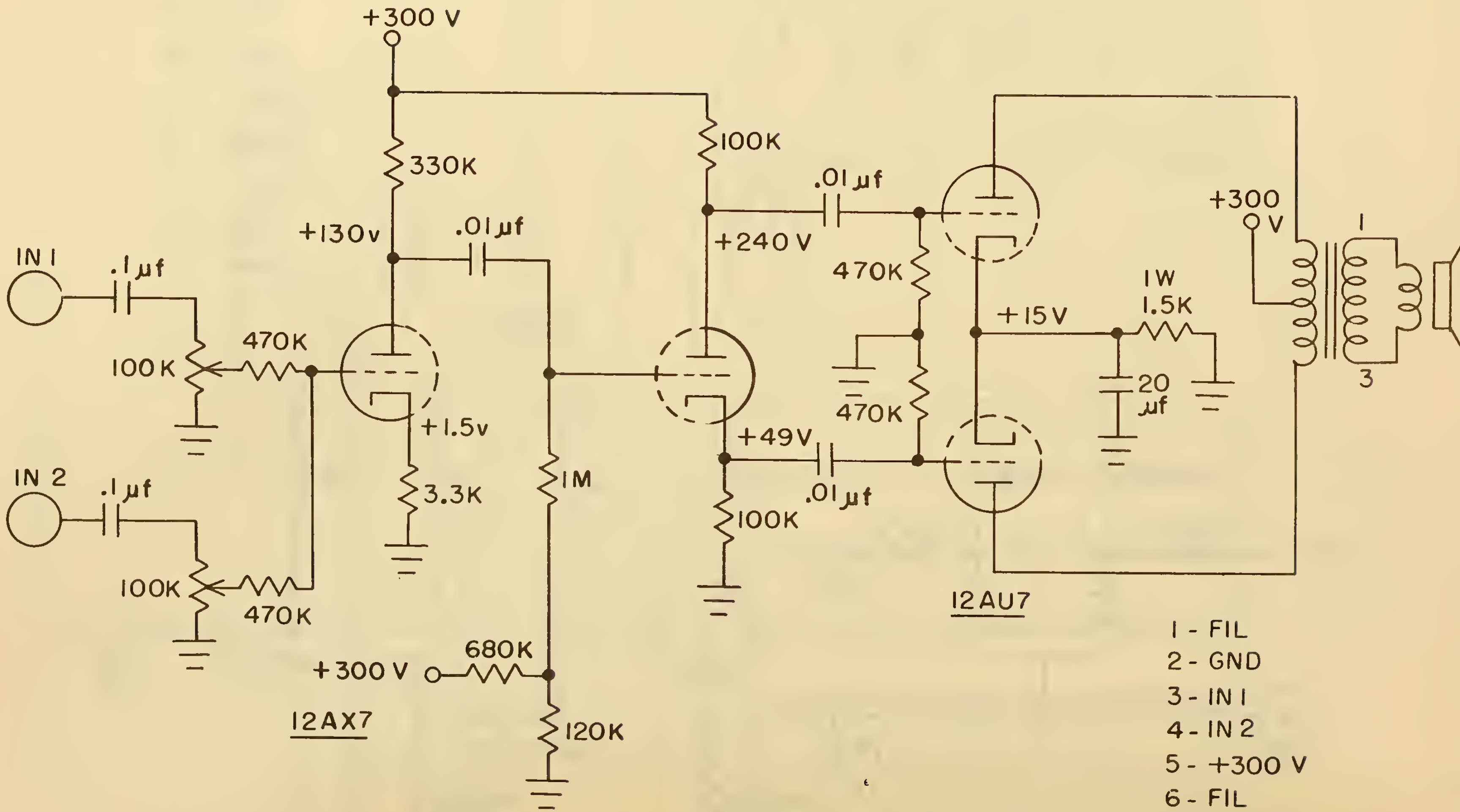


FIGURE 6. AUDIO AMPLIFIER

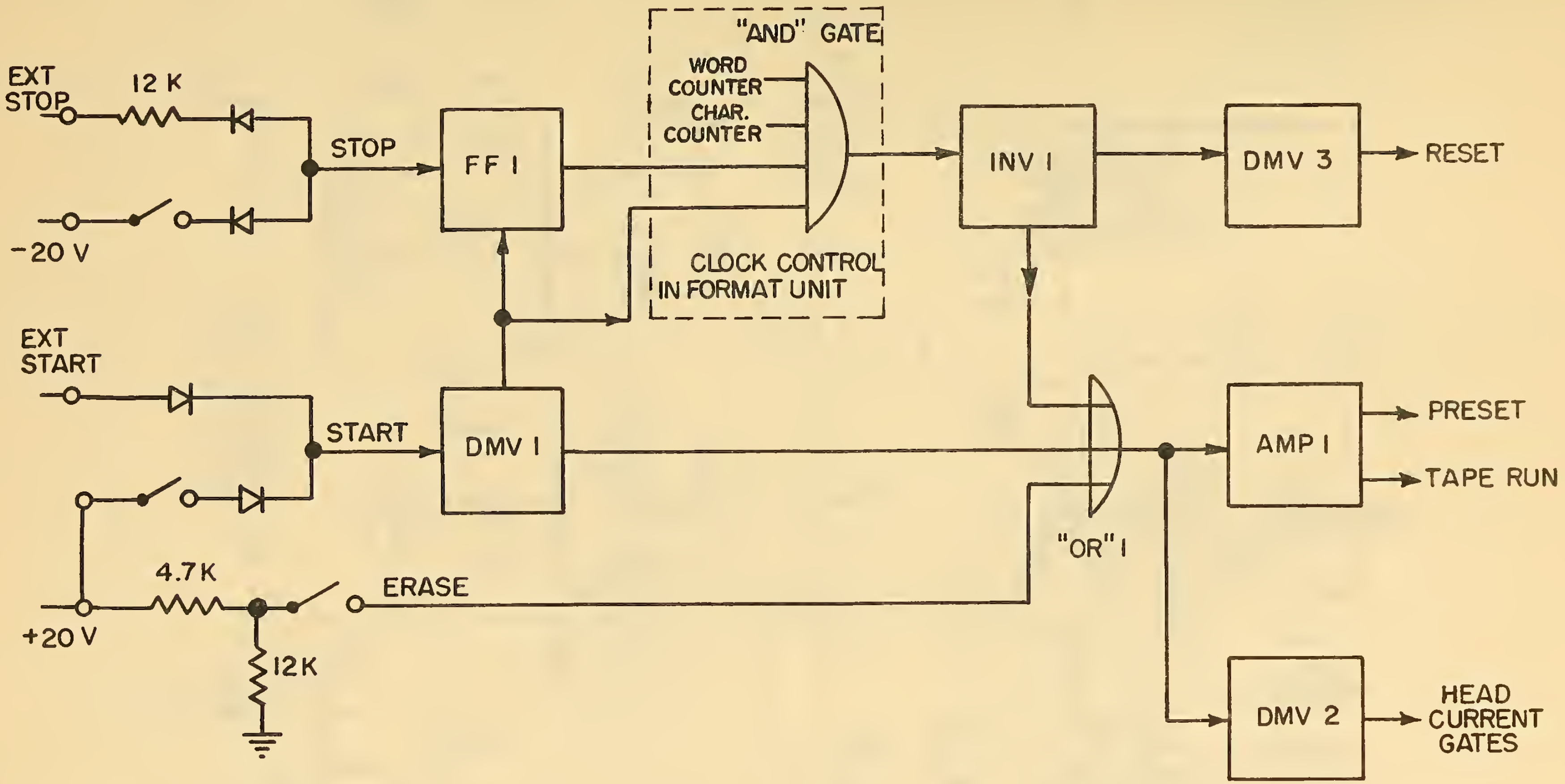


FIGURE 7. TAPE CONTROL BLOCK DIAGRAM

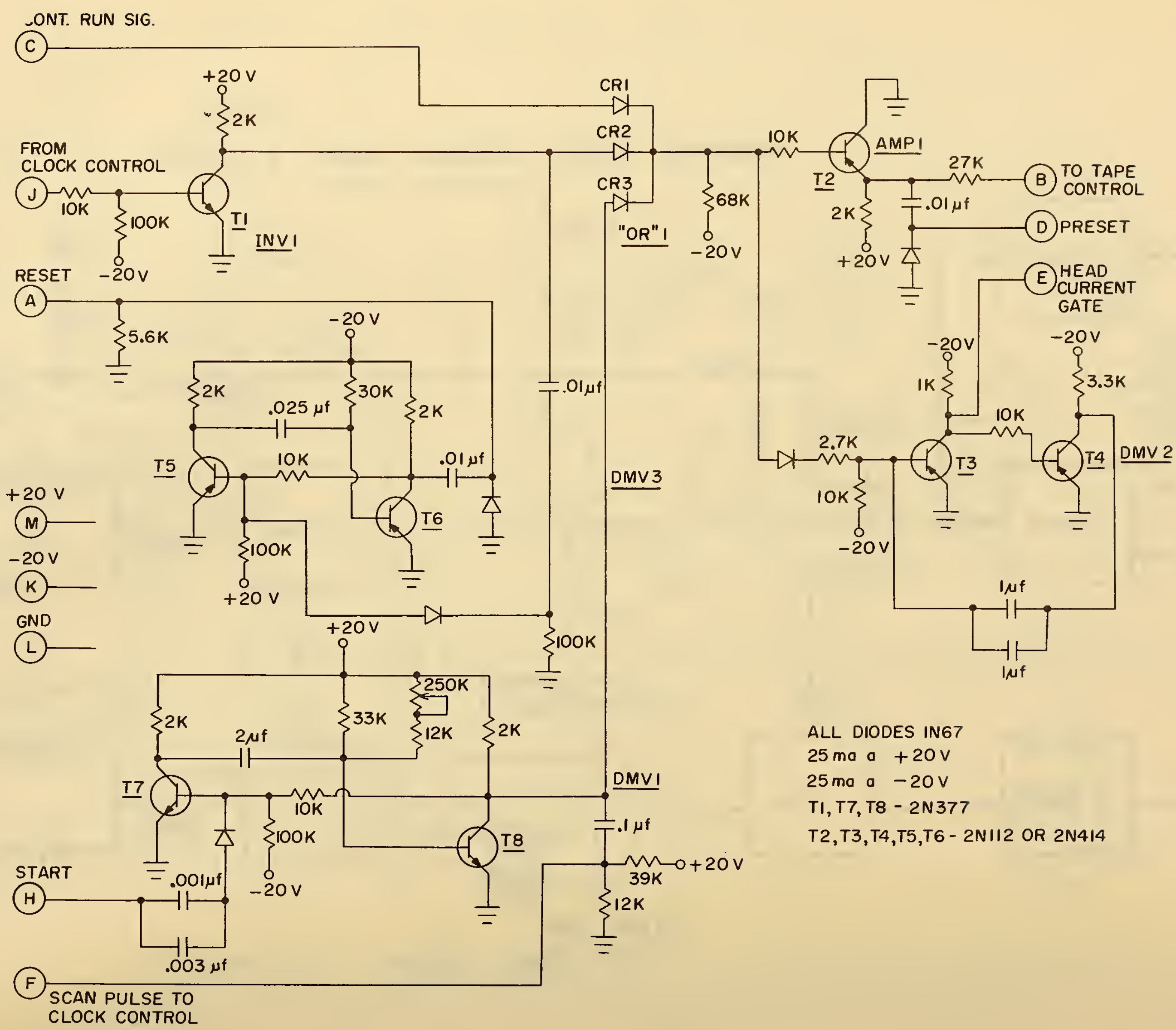


FIGURE 8. TAPE CONTROL CIRCUITRY

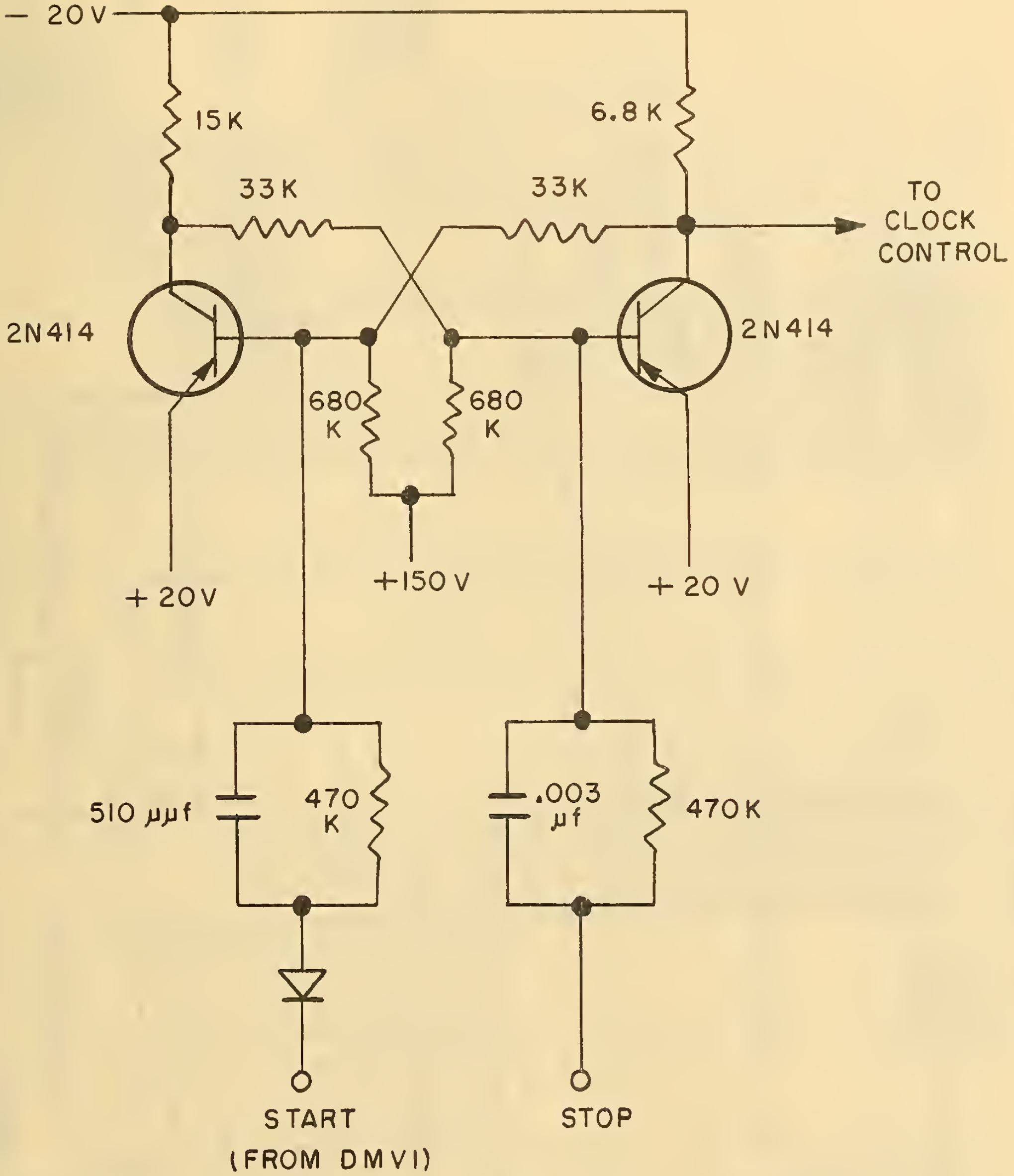


FIGURE 9. TAPE CONTROL FLIP - FLOP

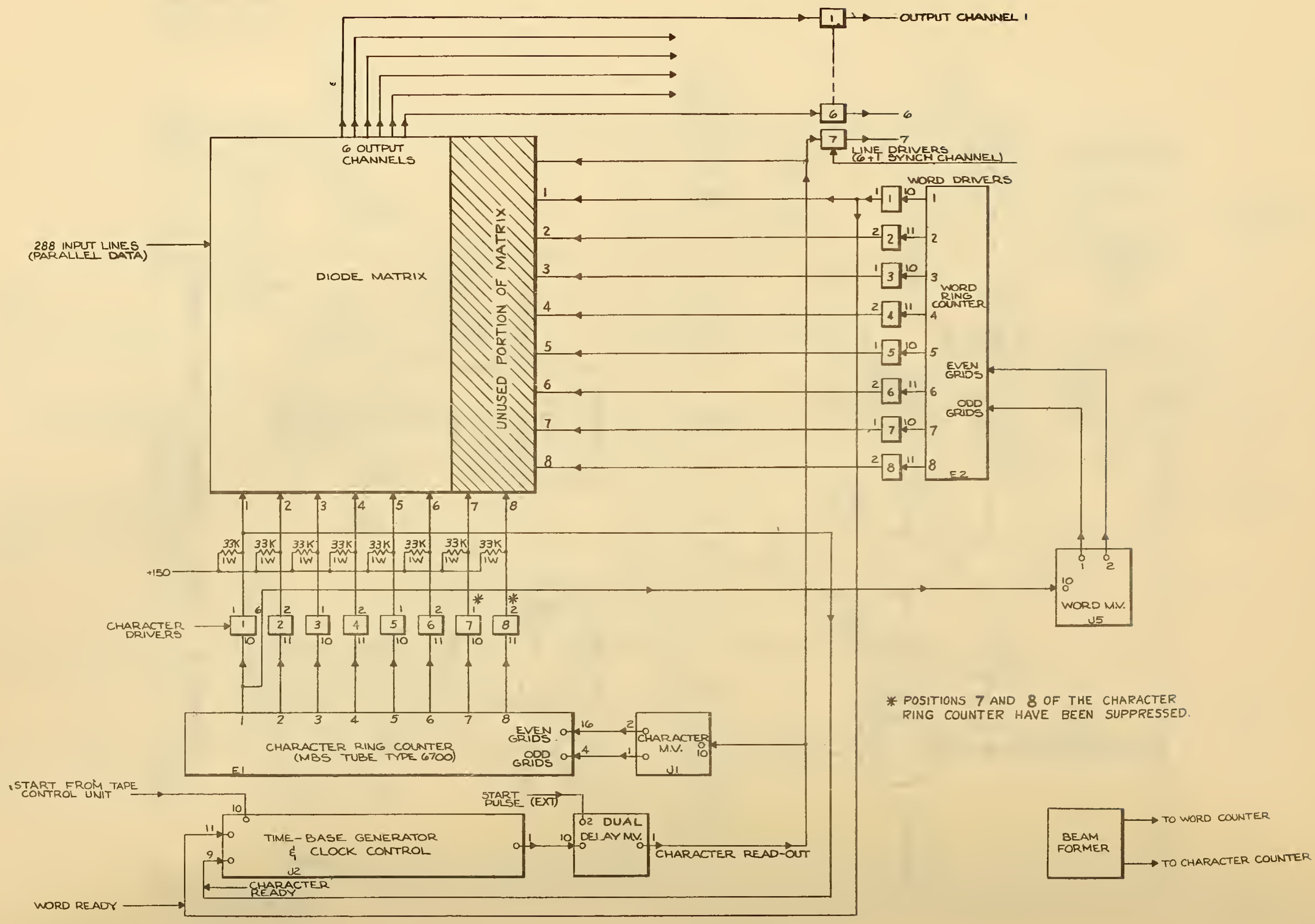


FIGURE 10. FORMAT CONTROL UNIT - BLOCK DIAGRAM

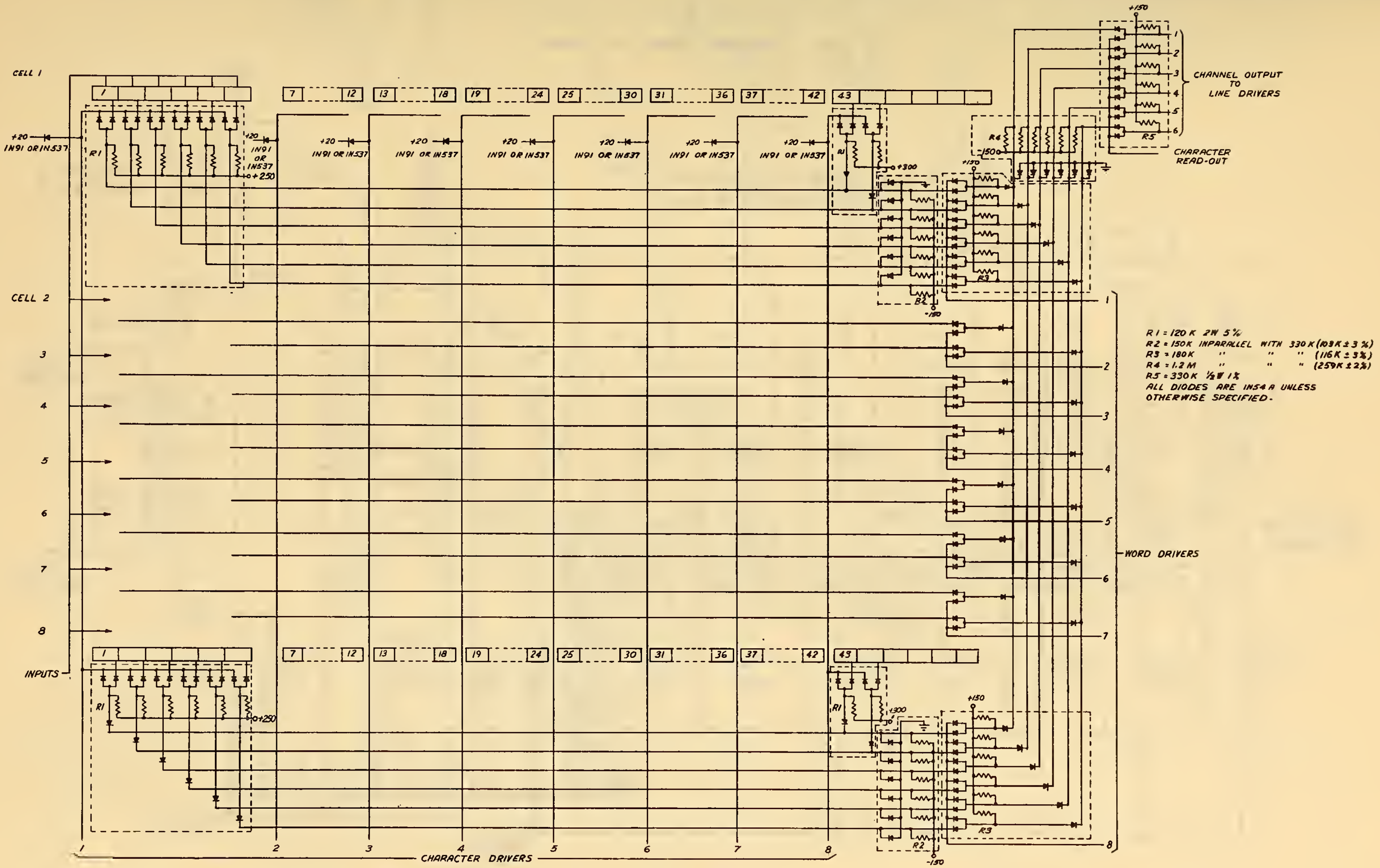


FIGURE 11. FORMAT CONTROL UNIT DIODE MATRIX CHASSIS SCHEMATIC.

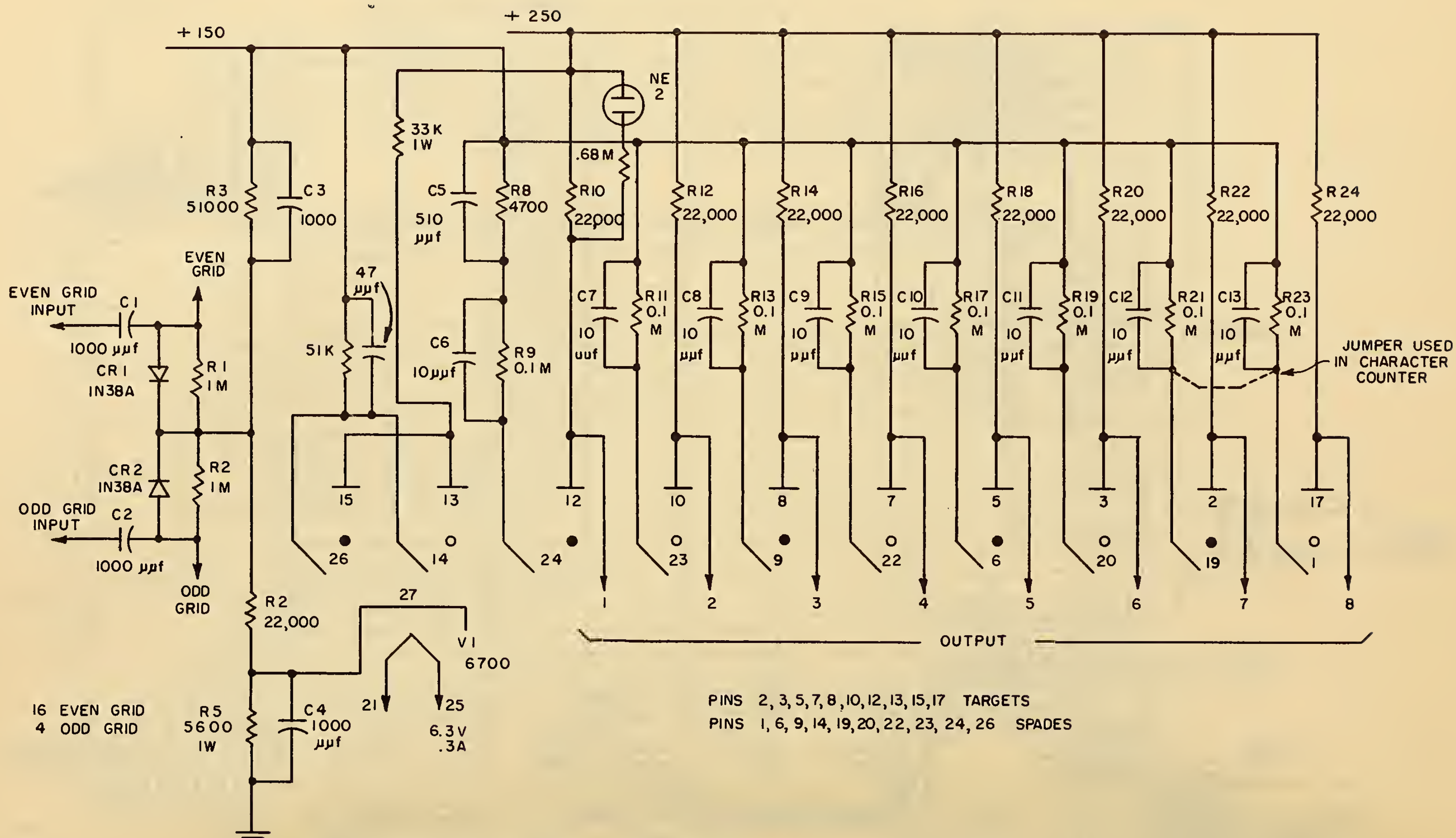


FIGURE 12. RING COUNTER

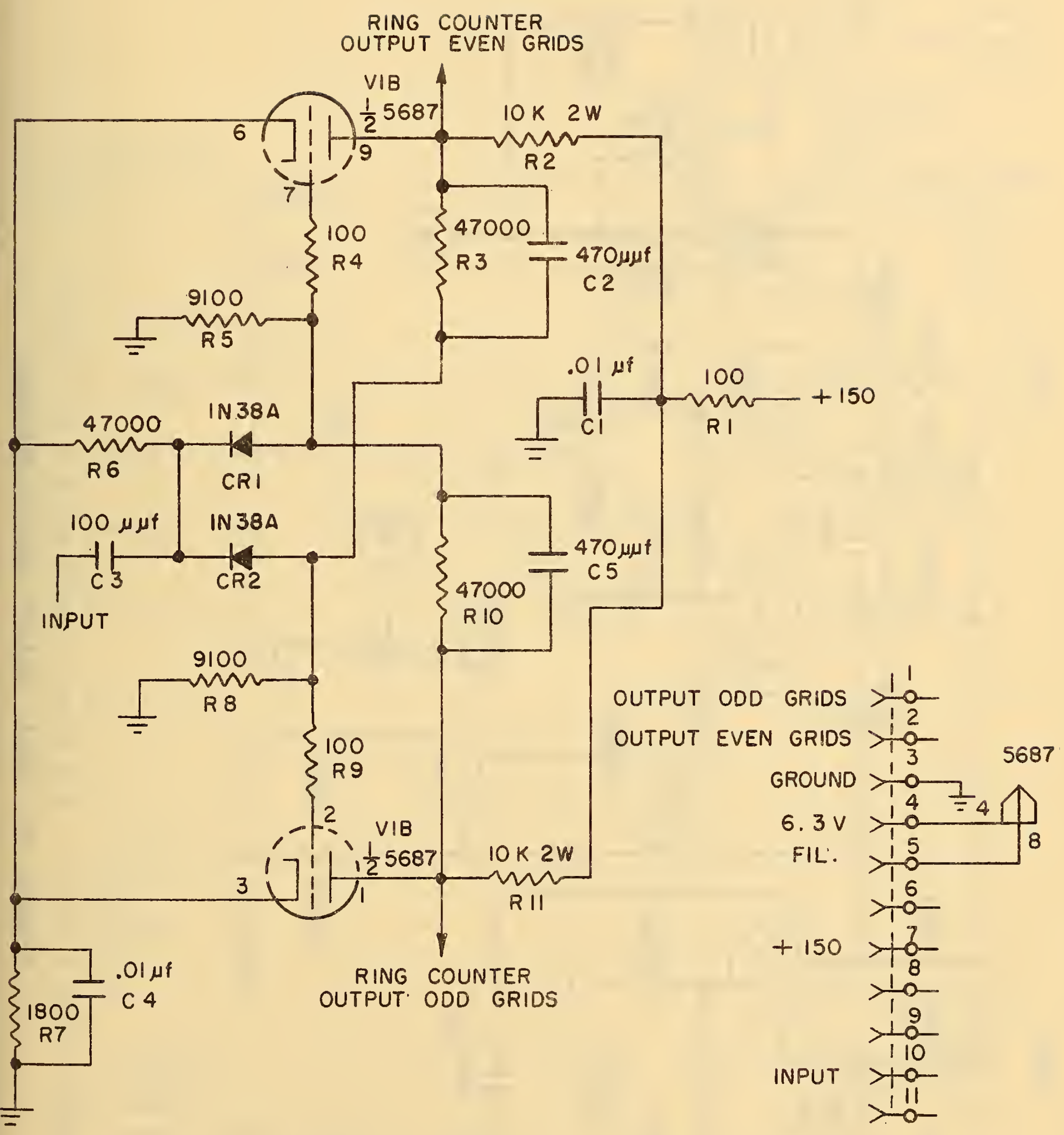


FIGURE 13. BI-STABLE MULTIVIBRATOR

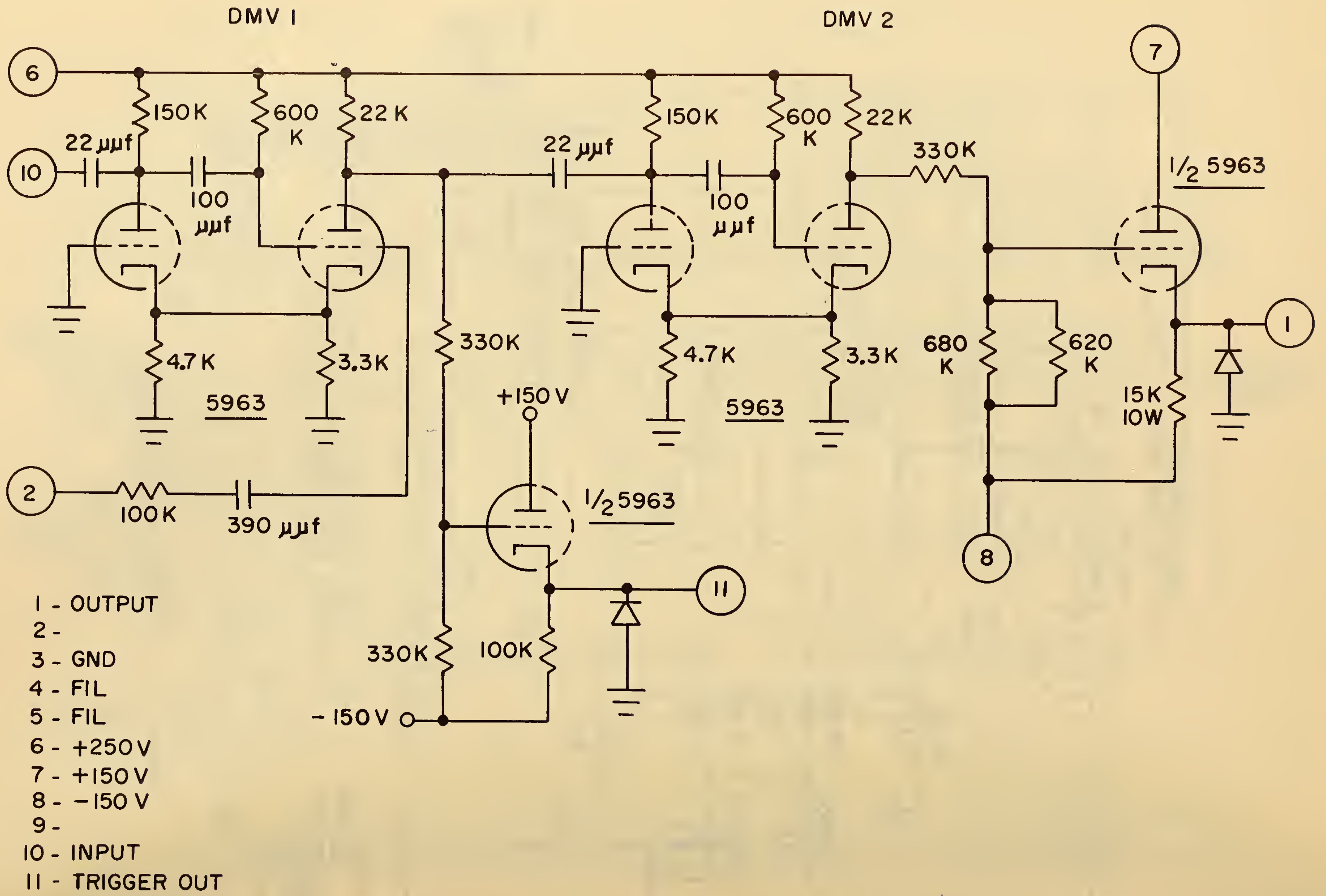
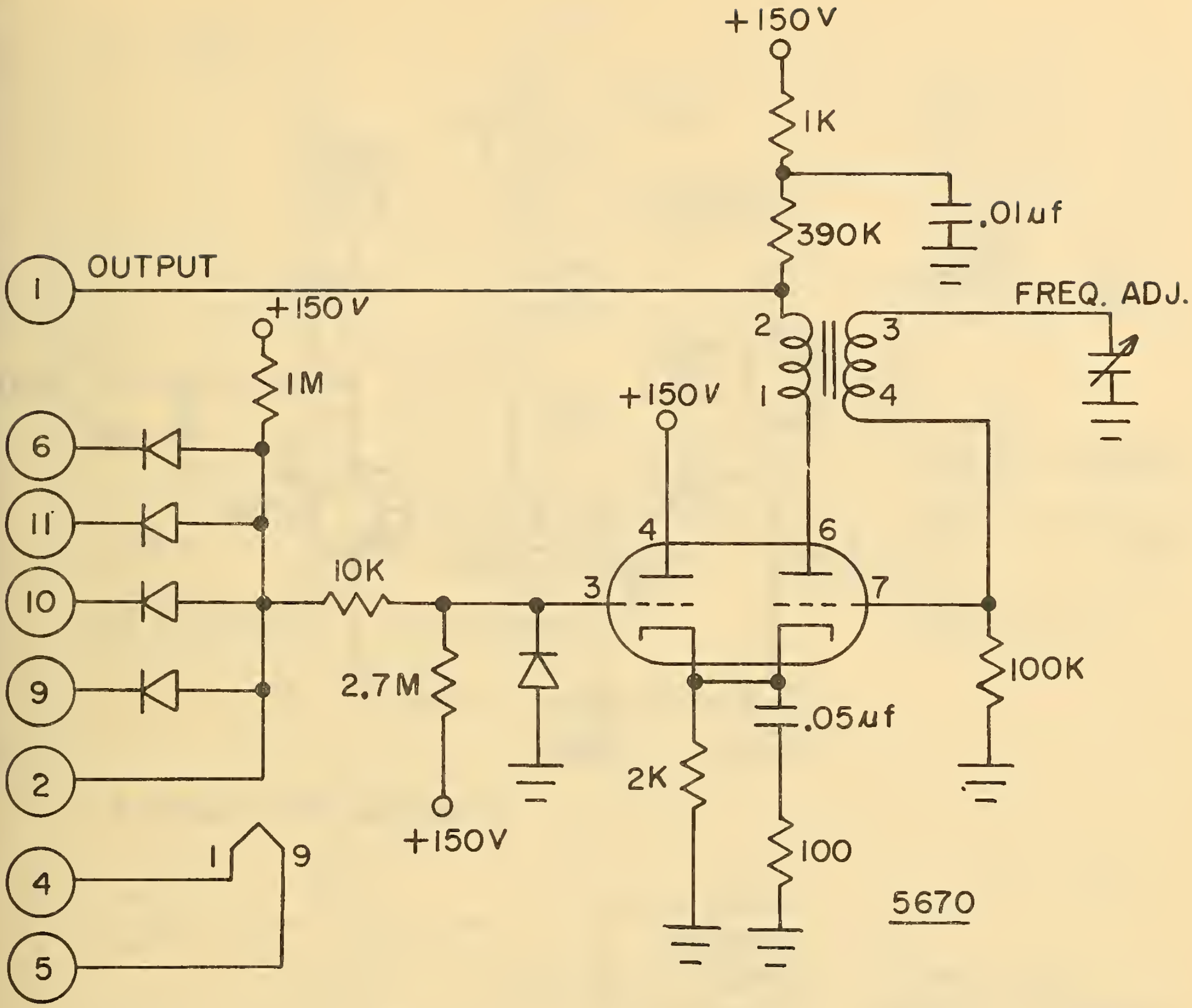
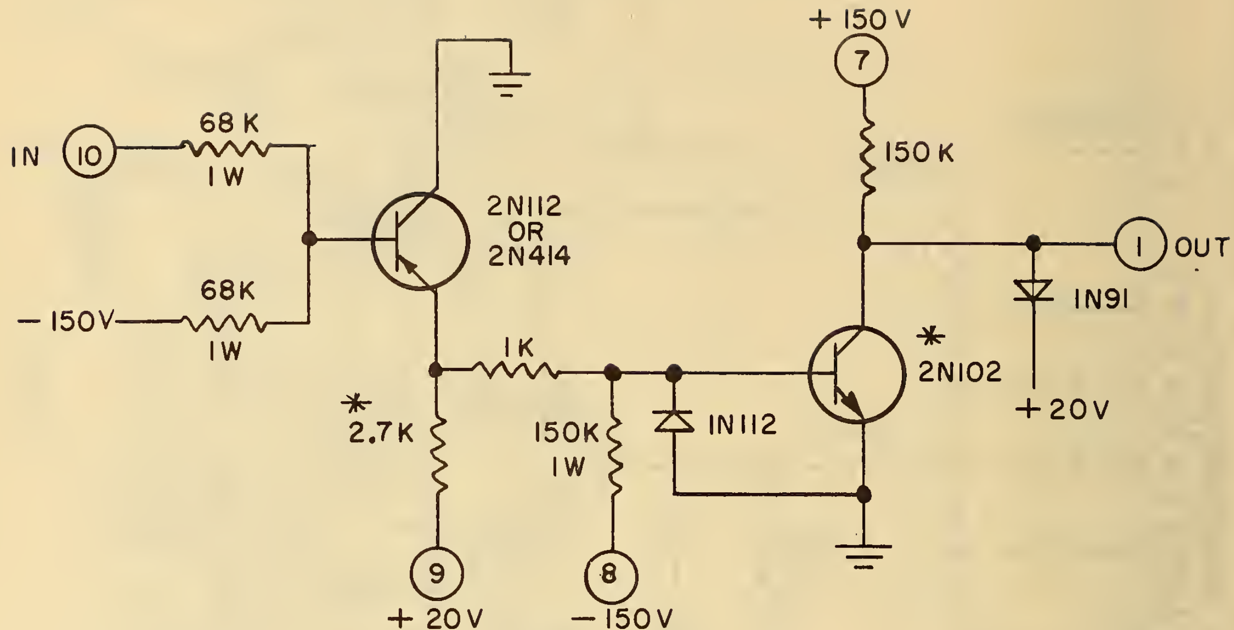


FIGURE 14. DUAL DELAY MULTIVIBRATOR



1 - OUTPUT
2 - T.P.
3 - GND.
4 - FIL
5 - FIL
6 -
7 - +150V
8 - −150V
9 - CHARACTER READY
10 - START, FROM TAPE CONTROL
11 - WORD READY

FIGURE 15. TIME BASE GENERATOR AND CLOCK CONTROL



2 DRIVERS PER PACKAGE

INPUT 1	10
OUTPUT 1	1
INPUT 2	11
OUTPUT 2	2
− 150 V	8
+ 150 V	7
+ 20 V	9
GROUND	3

NOTE:

* 2N377 MAY BE USED TO REPLACE 2N102. 2.7K CHANGED TO 1.8 K WITH 2N377.

FIGURE 16. CHARACTER AND WORD DRIVER

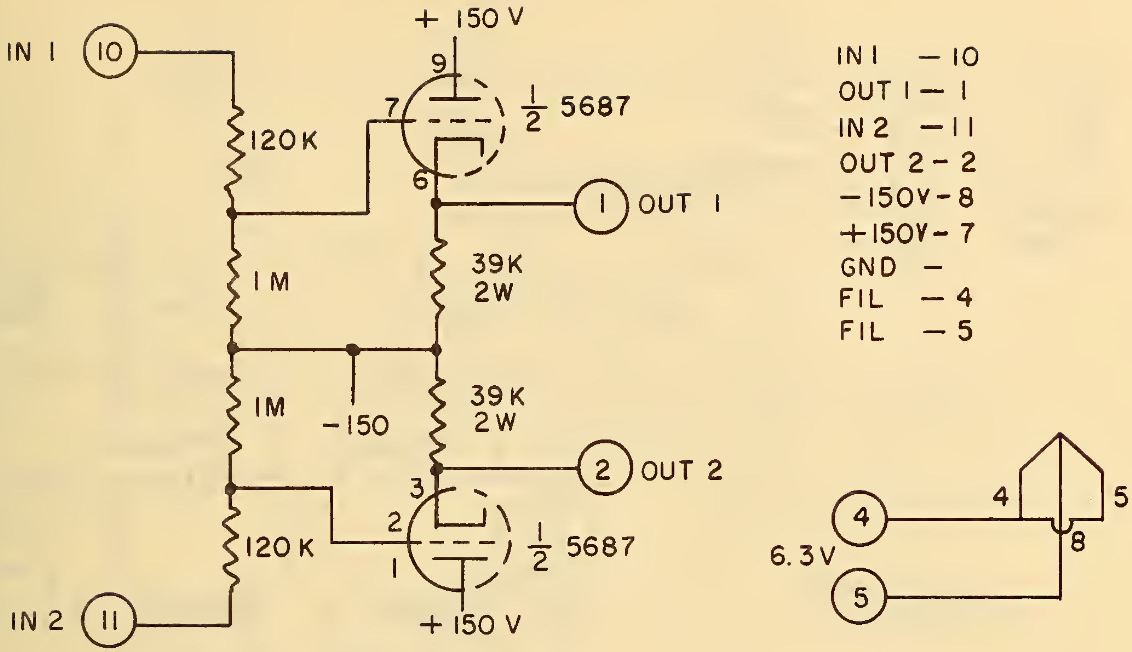
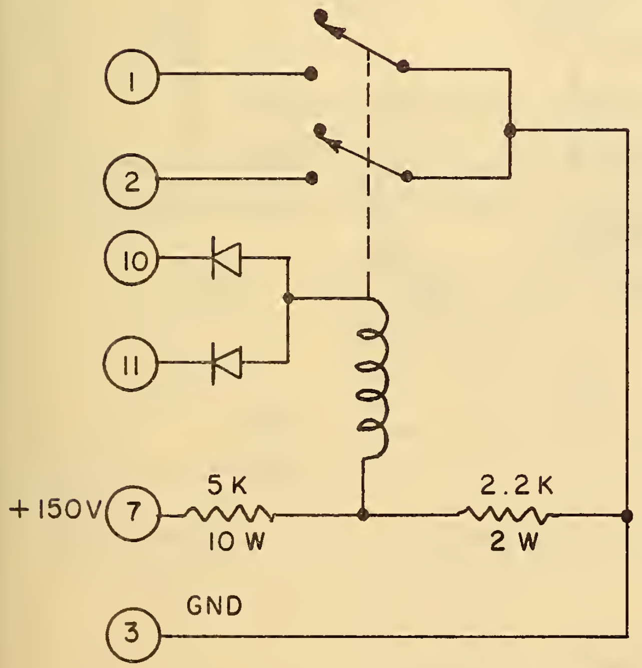


FIGURE 17. LINE DRIVER



1 — "1" SPADE OF CHARACTER COUNTER

2 — "1" SPADE OF WORD COUNTER

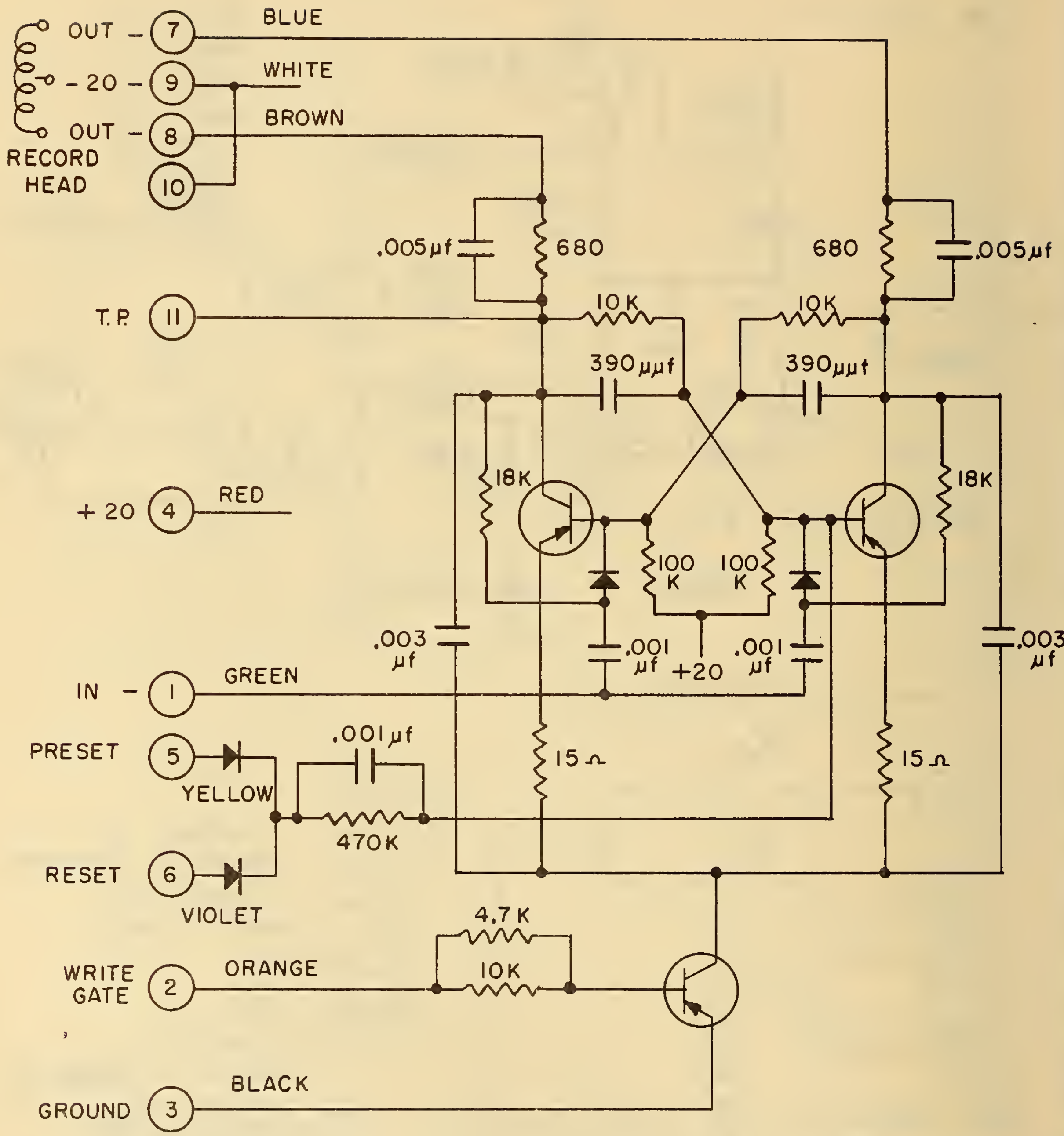
3 — GND

7 — +150 V DC

10 — CATHODE OF CHARACTER COUNTER

11 — CATHODE OF WORD COUNTER

FIGURE 18. BEAM FORMER



NOTE:
ALL TRANSISTORS 2N112 OR 2N414.
ALL DIODES IN67.

FIGURE 19. HEAD DRIVER

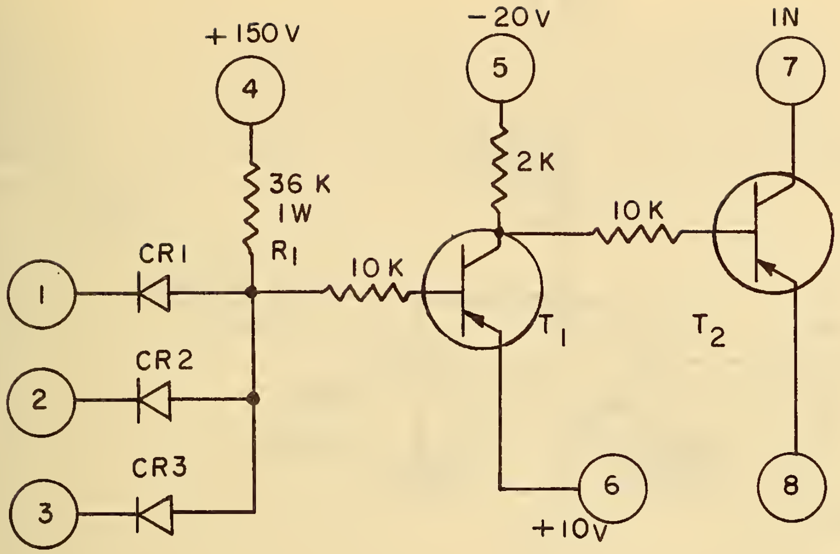


FIGURE 20. ANALOG GATE

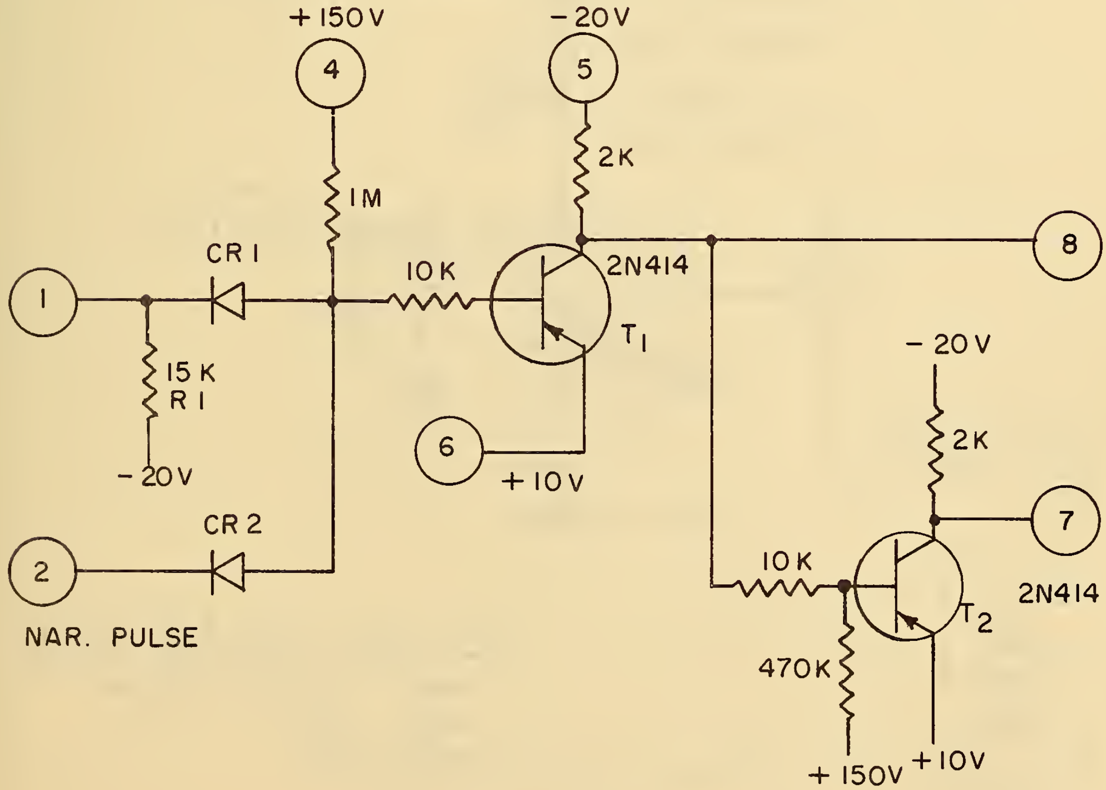
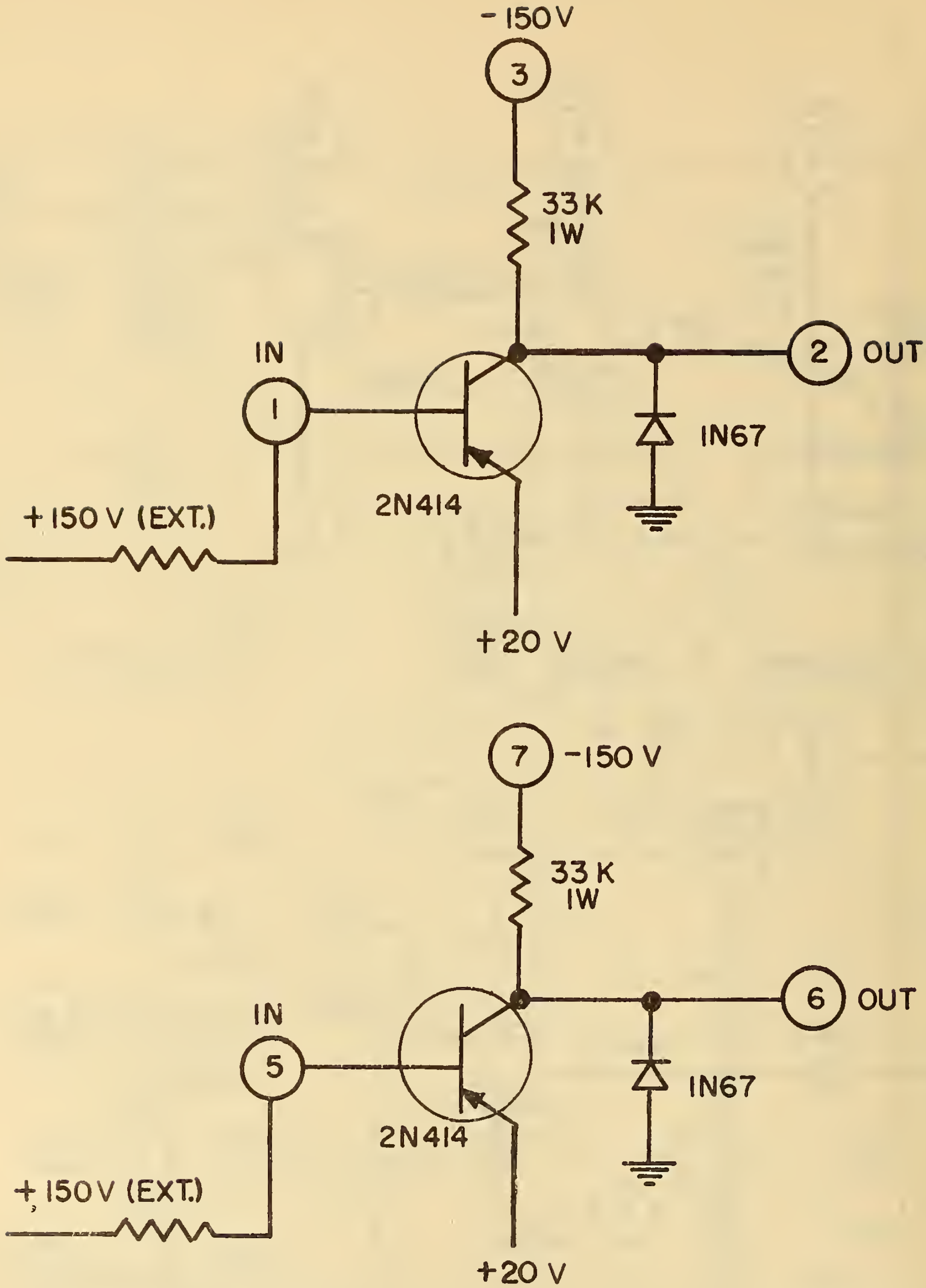


FIGURE 21. TRIGGER GENERATOR

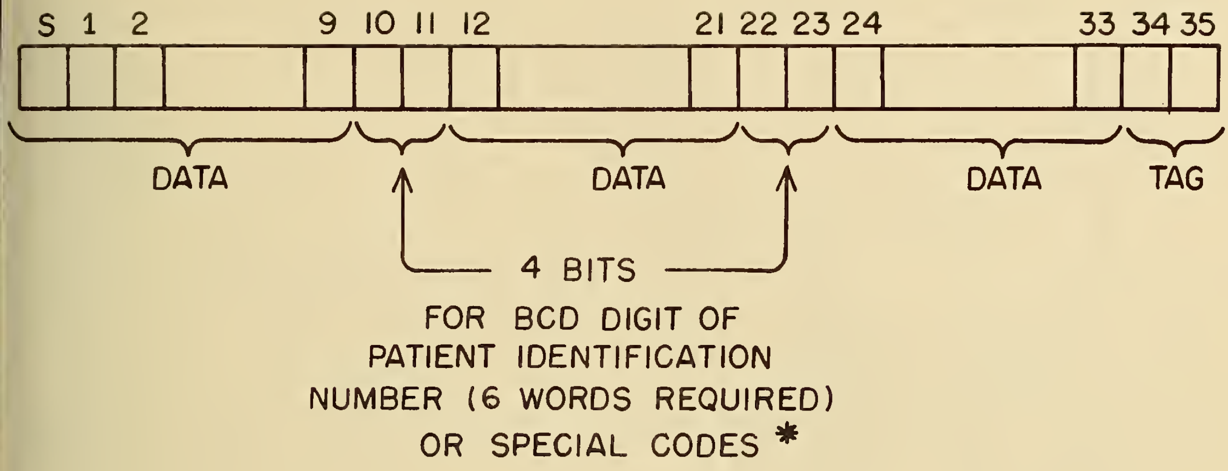


1 - IN 1
2 - OUT 1
3 - -150 V
4 - GND
5 - IN 2
6 - OUT 2
7 - -150 V
8 - +20 V

EXT. EPSCO BIAS RES: TO +150

68 K - 1, 4, 7, 8, 9 SIGN
100 K - 0, 3, 6
150 K - 2, 5

FIGURE 22. BUFFER



TAG CODE	DATA TYPE
0 0	ARTERIAL PRESSURE
0 1	PHONOCARDIOGRAM
1 0	BALLISTOGRAM
1 1	ELECTROCARDIOGRAM

* SPECIAL CODES

1010 – SPARE
1011 – SPARE
1100 – DELETE BLOCK
1101 – TAPE END
1110 – SPARE
1111 – CALIBRATION

FIGURE 23. WORD FORMAT

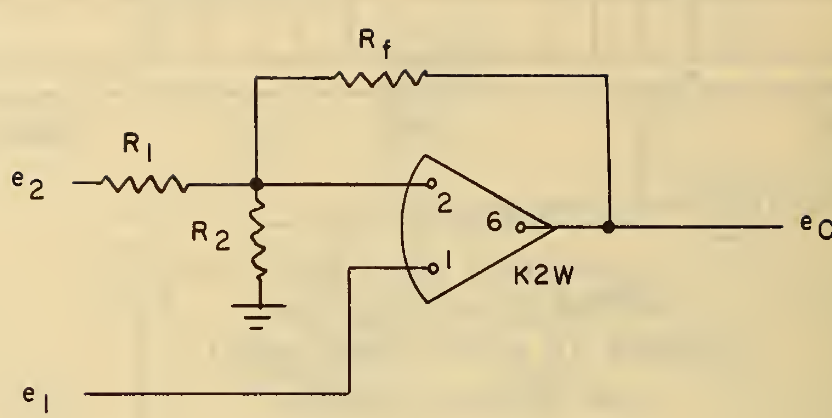


FIGURE 24. K 2 W OPERATIONAL AMPLIFIER

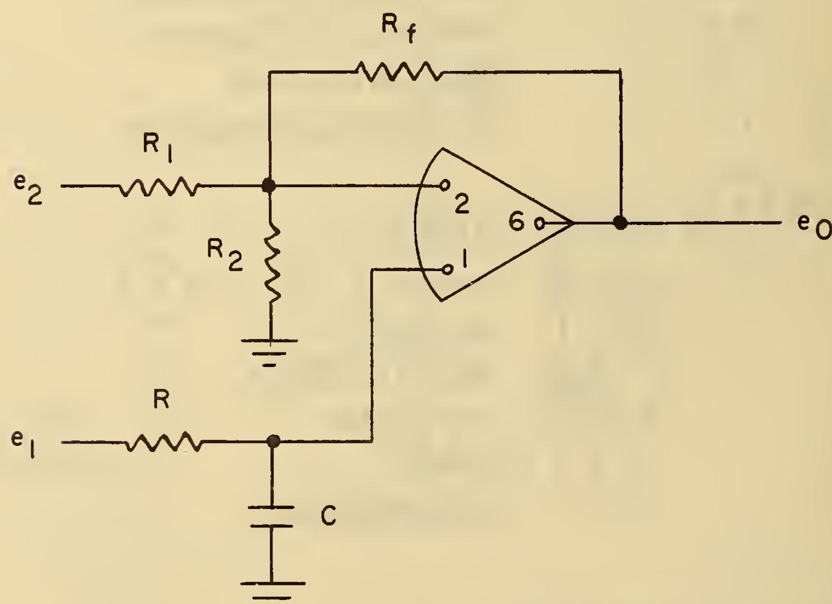


FIGURE 25. AMPLIFIER WITH DELAY

USCOMM--D

U.S. DEPARTMENT OF COMMERCE
Frederick H. Mueller, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

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Optics and Metrology. Photometry and Colorimetry. Photographic Technology. Length. Engineering Metrology.

Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Molecular Kinetics. Free Radicals Research.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Radiation Theory. Radioactivity. X-rays. High Energy Radiation. Nucleonic Instrumentation. Radiological Equipment.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer. Concreting Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

• Office of Basic Instrumentation. • Office of Weights and Measures.

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Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Research. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation Obstacles Engineering. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Electronic Calibration Center. Microwave Physics. Microwave Circuit Standards.

Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Ultra High Frequency and Super High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

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